WATER CLARIFICATION USING MORINGA OLEIFERA SEEDS

By

EMMANUEL OWUSU KISSI BSc. (Hons.)

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I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

EMMANUEL OWUSU KISSI	....	09-05-2010
(PG 9404006)	Signature	Date

Certified by:

DR. A. A. ADJAOTTOR	....	09/05/2010
Supervisor Name	Signature	Date

DR. A. A. ADJAOTTOR	....	09/05/2010
Head of Dept. Name	Signature	Date

ABSTRACT

Moringa oleifera is a tropical plant which has excellent coagulation properties for treating water and wastewater. The efficiency and properties of *Moringa oleifera* as a natural coagulant in water treatment were studied and compared with alum. The optimum concentration of *Moringa oleifera* was investigated for different levels of turbidity and the optimum settling time monitored.

Unlike alum, Moringa does not significantly affect the pH and alkalinity of the water after the treatment. Sludge produced by coagulation with *Moringa oleifera* is two to three times less in weight than the chemical sludge produced by alum coagulation. An average settling time of 2 hours was obtained for *Moringa oleifera* as compared to 1 hour for alum. The *Moringa oleifera* and alum increased the hardness of the treated water. The optimum *Moringa oleifera* concentration for the treatment of water was 3g/100 ml.

The percentage reductions with *Moringa oleifera* were 61.9% to 94.3% for turbidity, 79.6% to 94.7% for colour and 78.1% to 95.7% for suspended solids whiles those for alum were 59.5% to 91.4% for turbidity, 73.3% to 94.5% for colour and 75.0% to 95.7% for suspended solids. The percentage removals of colour, turbidity and suspended solids at the lower dosages of 55 ml and 60 ml were very higher for *Moringa oleifera* than alum. The percentage removal of colour, turbidity and suspended solids by Moringa and alum increase with increasing dosage of alum and Moringa. The coagulation efficiency of *Moringa oleifera* was found to be dependent on initial turbidity of water samples. Highest turbidity removals were obtained for water with high initial turbidity.

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1 INTRODUCTION

1.1 BACKGROUND

Access to safe drinking water is important as a health and developmental issue at a national, regional and local level. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, since the reductions in adverse health effects and health care costs outweigh the costs of undertaking the interventions (WHO, 2004). This is true for major water supply infrastructure investments compared to water treatment in the home. Experience has also shown that interventions in improving access to safe water favour the poor in particular, whether in rural or urban areas, and can be an effective part of poverty alleviation strategies. However, it is a tragedy that 42% of the world's population, or 2.6 billion people, live in families with no proper means of sanitation and 1.1 billion do not have access to improved drinking water with about 4500 children dying every day and sentencing their siblings, parents and neighbours to sickness, squalor and enduring poverty (WHO/UNICEF, 2005). There are a number of reasons for the persistence of these problems, in spite of the investment of billions of dollars in safe water by donor agencies and governments. The rapid population growth, both in rural and urban areas, has pressured existing water supply systems. This is accompanied by the sustainability of operation and maintenance of water supply infrastructure that has hindered access to water by the poor in many developing countries. The situation is again aggravated by deterioration of the quality of water resources, attributed to the direct industrial and municipal waste discharge rendering existing treatment units ineffective to meet the water quality standards, both on a national and World Health organization level. Large consumption of imported chemicals like alum and chlorine used in the treatment of water renders water expensive. Consequently, the poor are forced to collect water from less safe sources, such as contaminated ponds.

Water purification is the removal of contaminants from raw water to produce drinking water that is pure enough for human consumption or for industrial use. Substances that are removed during the process include parasites (such as Giardia or Cryptosporidium), bacteria, algae, fungi, minerals (including toxic metals such as lead, copper etc.), and man-made chemical pollutants. Many contaminants can be dangerous but depending on the quality of standards, others are removed to improve the water's smell, taste, and appearance. A small amount of disinfectant is usually intentionally left in the water at the end of the treatment process to reduce the risk of re-contamination in the distribution system (Encarta, 2006).

The Barekese water headwork supplies potable water to the Kumasi metropolis and its environs. The capacity of the plant is 18,000,000 gallons per day. The source of water supply is the River Offin. The dam was constructed in 1965 and commissioned in 1969.

The removal of organic and inorganic material from raw water is essential before it can be disinfected for human consumption. In a water treatment works, this clarification stage is normally achieved by the application of chemical coagulants which change the water from a liquid to a semi-solid state. This is usually followed by flocculation, the process of gentle and continuous stirring of coagulated water, which encourages the formation of flocs. Flocs can be easily removed by settling or filtration. For many communities in developing countries, however, the use of coagulation, flocculation and sedimentation is inappropriate because of the high cost and low availability of chemical coagulants, such as aluminium sulphate and ferric salts (Akhtar et al., 2006, Sharma et al., 2006).

The application of an indigenous, naturally-derived coagulant, namely seed material from the multi-purpose tree *Moringa oleifera* (*M. oleifera*) offers an alternative solution to the use of expensive chemical coagulants. Studies undertaken by Leicester University Engineering Department (1994) have shown that seeds of *Moringa oleifera* could be used to treat water with removal efficiencies of 90-99% for turbidity and pathogens.

The present study, therefore, seeks to compare optimum treatment performance of different concentrates of *Moringa oleifera* upon application and also compare performance of *Moringa oleifera* and alum on water treatment. Achievement of this aim will help in reducing over-reliance on imported water treatment chemicals, cost of water production and thereby lead to improvement in health and economic activities of rural people.

1.2 STATEMENT OF PROBLEM

More than nine million people have no access to safe drinking water in Ghana (WHO/UNICEF, 2005). In addition to food, clothing, and shelter, water is one of our basic human needs and the lack of potable water is a major cause of death and disease in our world (Doerr Beth, 2005). Waterborne diseases are one of the main problems in developing countries. About 1.6 million people in the world are compelled to use contaminated water (Schwarz Dishna, 2000). However, in many communities of these developing countries water clarification methods of coagulation, flocculation and sedimentation are often inappropriate because of the high cost and low availability of chemical coagulants.

River water taken for household use can be full of suspended matter, particularly in the rainy season. The water carries silt particles, solids, bacteria and other micro-organisms (some of which can carry disease). It is very important to remove as much of this material as possible prior to use of the water. Large water treatment centers do this by adding chemical coagulants to the water. These cause the particles to stick together (coagulate) and settle. The clean water can then be poured off. The chemicals, however, may be unavailable or too expensive. The use of natural materials of plant origin to clarify turbid water is not a new idea. Among all the plant materials that have been tested over the years, the seeds from *Moringa oleifeira* have been shown to be one of the most effective as a primary coagulant for water treatment and can be compared to those of alum (Schwarz Dishna, 2000).

1.3 JUSTIFICATION

Access to safe drinking-water is important as a health and developmental issue at the national, regional and local levels.

More than nine million people have no access to safe drinking water in Ghana (WHO/UNICEF, 2005).

The UN General Assembly declared 2005 to 2015 as the International Decade for Action, "Water for Life".

Turbidity removal is one of the important steps in a water treatment process, which is generally achieved using coagulants. The two most commonly used primary coagulants are Aluminium and Iron (III) salts (Okuda et al., 1999). However, recent studies have pointed out several serious drawbacks of using Aluminium salts, such as Alzheimers disease associated with residual Aluminium in treated water and production of large sludge volumes (Ndbigengsere and Narasiah, 1998a). There is also the problem of reaction of alum with natural alkalinity present in the water leading to a reduction of pH and low efficiency in coagulation in cold water (Haarhoff and Cleasby, 1988). In addition, the use of alum and iron salts is limited in some developing countries because of the high cost and low availability of chemical coagulants (Schultz and Okun, 1983).

1.4 OBJECTIVES

The objectives of this research are:

- To determine optimum treatment performance of different concentrates of *Moringa oleifera* upon application.
- To investigate Optimum time for *Moringa oleifera* on water treatment.
- Compare the performance of *Moringa oleifera* and alum on water treatment.

2. LITERATURE REVIEW

2.1 CONVENTIONAL DRINKING WATER TREATMENT

Most urban communities collect water from a natural water body in the catchment, whether a stream, river, or underground aquifer. The water collected may then be stored in a reservoir for sometime. Unless it is already of very high quality, it then undergoes various water treatment processes that remove chemicals, organic substances or organisms that could be harmful to human health. The most widely applied water treatment technology is a combination of some or all of coagulation, flocculation, sedimentation and filtration. No single process can, however, solve every water quality problem. Therefore, the treatment technology or combination of technologies to be used in a specific situation depends on the types of water quality problems likely to be present, the nature of the contaminant to be removed, the desired qualities of the treated water, the costs of different treatments and the size of the water system.

2.2 RECOMMENDED VALUES FOR DRINKING WATER

The values for different parameters of good drinking water are presented in Table 2.1 below.

Table 2.1: Recommended values in drinking water

SUBSTANCE OR PROPERTY	MAXIMUM DESIRABLE CONCENTRATION	MAXIMUM PERMISSIBLE CONCENTRATION
Total solids	500 mg/l	1500 mg/l
Turbidity	5 NTU	25 NTU
pH	7 to 8.5	6.5 to 9.2
Total hardness	100 mg $CaCO_3$ / l	100 mg $CaCO_3$ /l
Calcium (Ca)	75 mg/l	200 mg/l
Manganese (Mn)	0.05 mg/l	0.5 mg/l
Iron (Fe)	0.1 mg/l	1.0 mg/l

SOURCE: (Arnoldsson and Bergman, 2007).

2.3 COAGULATION AND FLOCCULATION

Historically, the terms "coagulation" and "flocculation" have been used interchangeably to describe the process of removal of turbidity from water. There is, however, a clear distinction between the two terms. The term "coagulation" comes from the Latin word *coagulare*, meaning to drive together. This process describes the effect produced by the addition of a chemical to a colloidal dispersion resulting in particle destabilization by a reduction of the force tending to keep the particles apart. Operationally, coagulation is achieved by adding the appropriate chemical, which causes particles to stick together when contact is made. Rapid mixing is important at this stage to obtain uniform dispersion of the chemical and to increase the opportunity for particle-to-particle contact. The entire process occurs in a very short time, probably less than a second, and initially results in particles submicroscopic in size.

The second stage of the formation of settleable particles from destabilized colloidal-sized particles is termed "flocculation". This term also has its derivation from the Latin word *flocculare*, meaning to form a floc, which visually resembles a tuft of wool or highly fibrous porous structure. In contrast to coagulation, where the primary force is electrostatic or interionic, flocculation occurs by a chemical bridging or physical enmeshment mechanism. Flocculation is operationally obtained by gentle and prolonged mixing which converts the submicroscopic coagulated particles into discrete, visible, suspended particles. At this stage, the particles are large enough to settle rapidly under influence of gravity and may be removed by filtration.

Coagulation is employed for the removal of waste materials in suspended or colloidal form. Colloids are particles within the size range of 1 nm (10^{-7} cm) to 0.1 nm (10^{-8} cm).

These particles do not settle out on standing and cannot be removed by conventional physical treatment processes. Colloids can be either hydrophobic or hydrophilic. The hydrophobic colloids (clays etc) possess no affinity for the liquid medium and lack stability in the presence of electrolytes. They easily coagulate. Hydrophilic colloids on the other hand, such as proteins, exhibit a marked affinity for water. This therefore requires special treatment for effective coagulation. Colloids possess electrical properties which create a repelling force and prevent agglomeration and settling. Ions of an opposite charge form a diffuse outer layer which is held near the surface by electrostatic forces. The stability of a colloid is due to the repulsive electrostatic forces. Since a vast majority of colloids in industrial wastes posses a negative charge, coagulation is induced by the addition of high-valence cations (Eckenfelder Wesley, 2000).

The psi (Ψ) potential is defined as the potential drop between the interface of the colloid and the body of the solution. The zeta (ξ) potential is the potential drop between the slipping plane and the body of the solution and is related to the particle charge and thickness of the double layer. The thickness of the double layer (x) is inversely proportional to the concentration and valence of nonspecific electrolytes, as shown if Figure 2.1 below.

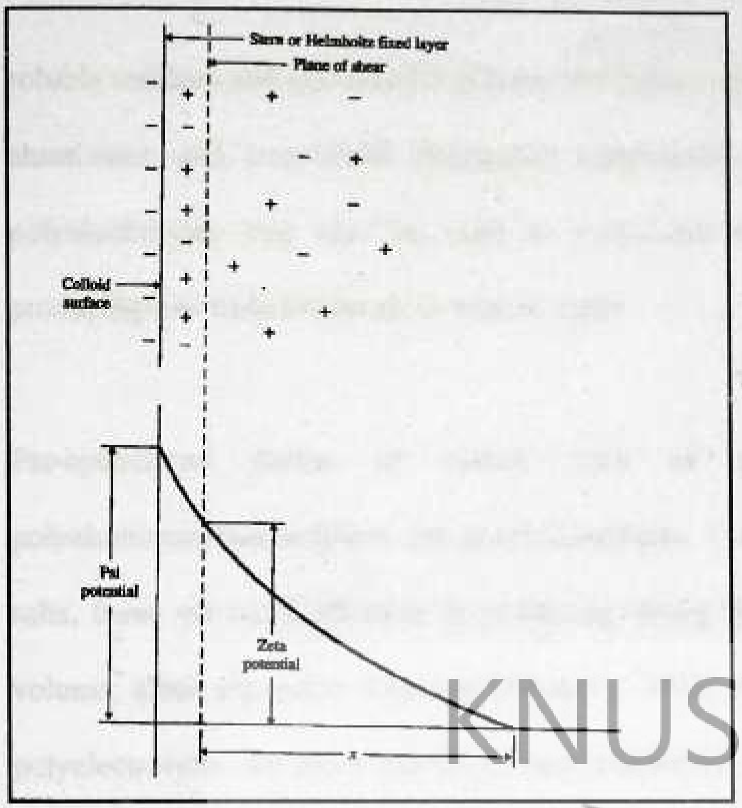

FIGURE 2.1: Electrochemical properties of colloidal particles.
SOURCE: (Eckenfelder Wesley, 2000).

2.4 COAGULANTS AND FLOCCULANTS

Coagulants are chemicals that assist the destabilization of particles (particularly of colloidal sizes). Hydrolysing metal salts, based on aluminium or iron, are very widely used as coagulants in water treatment. The high cationic charge makes them effective for destabilising colloids. These salts bring about destabilisation by adsorption and charge neutralization as well as by particle entrapment (Duan and Gregory, 2003). Flocculants (also known as flocculant aids or coagulant aids) assist in the joining and enmeshing of the particles together. As a flocculant aid the chemical is added following coagulant dosing to increase the size, strength and settleability of flocs. Flocculants may be cationic, anionic or non-ionic. They are produced with varying degrees of ionicity and in a range of molecular weights. Although these chemicals are effectively and widely used, they have drawbacks: they influence the pH of the water, increase the soluble residues and increase the volume and metal content of the sludge. In addition to aluminium and iron-based (inorganic) coagulants, organic chemicals known as polyelectrolytes may also be used as coagulants or flocculant aids, to assist in producing low turbidity levels in treated water.

Pre-hydrolysed forms of metals such as polyaluminium chloride and polyaluminosilcate sulphate are good coagulants. Compared to aluminium and iron salts, these are more effective in producing strong flocs and resulting in less sludge volume, albeit expensive (Duan and Gregory, 2003). Although, based on material cost, polyelectrolytes are more expensive than aluminium and iron salts, overall operating costs can be lower because of reduced need for pH adjustment, lower sludge volumes and reduced disposal costs. However, they may not be readily available to some of the developing parts of the world and even if they are, the costs may be prohibitive.

2.5 MECHANISM OF COAGULATION

Coagulation results from two basic mechanisms: (i) Perikinetics and (ii) Orthokinetic coagulation.

I. Perikinetic (or electrokinetic) coagulation, in which the zeta potential is reduced by ions or colloids of opposite charge to a level below the van der Waals attractive forces.

II. Orthokinetic coagulation occurs when micelles aggregate and form clumps that agglomerate the colloidal particles.

The addition of high - valence cations depresses the particle charge and the effective distance of the double layer, thereby reducing the zeta potential. The cations of the coagulant neutralize the negative charge on the colloids. Microflocs are formed which retain a positive charge. These microflocs also serve to neutralize and coat the colloidal particles. Flocculation agglomerates the colloids. A desired sequence of operation for effective coagulation is as follows:

I. Bicarbonate added without effectively raising the pH: it provides alkalinity without raising the pH.

II. Alum or ferric salts are added: they coat the colloids with Al^{3+} or Fe^{3+} ions and generate positively charged microflocs.

III. Coagulant aids, such as activated silica and / or polyelectrolyte are added to build up flocs and control the zeta potential.

After adding the alkali and coagulant, the mixture is stirred rapidly for 1-3min. Flocculation follows on adding coagulant aid and allowing settling for 20-30 minutes. Polymers are 10-15 times more effective than alum as a coagulant but are considerably more expensive (Eckenfelder Wesley, 2000).

2.6 NEED FOR COAGULATION

With relatively few exceptions, surface waters require some kind of treatment before distribution to consumers. Contaminants resulting from land erosion, dissolution of minerals, and the decay of organic vegetation have always been present in widely varying proportions in streams and have required removal to make the water potable. The need for such treatment is ever increasing because of the additional pollution contributed by an expanding industrial complex and a burgeoning human population (AWWA, 1999).

Natural waters polluted either by man or by nature, are likely to contain dissolved inorganic and organic substances, biological forms such as bacteria and plankton, and suspended inorganic material. To remove these substances, the usual unit processes include plain sedimentation, removal by coagulation generally followed by filtration, and chemical precipitation are used generally to remove dissolved minerals like hardness components and iron and manganese.

Coagulation, generally followed by filtration, is by far the most widely used process to remove the substances producing turbidity in water. It is the process for combining small particles into larger aggregates through the addition of a chemical. The substances which normally produce turbidity consist largely of clay minerals and microscopic organisms and occur in widely varying sizes, ranging from those large enough to settle readily to those small enough to remain suspended for very long times.

Coarser components, such as sand and silt, can be removed from water by simple sedimentation. Finer particles, however, will not settle in any reasonable time and must be flocculated to produce the large particles that are settleable. The long-term ability to remain suspended in water is basically illustrated in Table 2, which shows the relative settling times of spheres of different sizes. It can be seen that the settling rates of the colloidal and finely divided (approximately 0.001 to 1 micron) suspended matter are so slow that removing them from water by plain sedimentation in tanks having ordinary dimensions is impossible. The enormous increase of surface area for a given weight of solids as the particles become smaller and more numerous is an important property of colloids.

TABLE 2.2: Effect of Decreasing Size of Spheres on Time of Settling

Diameter of particles, mm	Order of size	Total surface area	Time required to settle
10	Gravel	3.14 cm^2	0.3 sec
1	Coarse sand	3.14 cm^2	3 sec
0.1	Fine sand	3.14 cm^2	38 sec
0.01	Silt	21.8 cm^2	33 min
0.001	Bacteria	218.0 cm^2	55 hr
0.0001	Colloidal particles	24.5 cm^2	230 days
0.00001	Colloidal particles	28329 m^2	6.3 yr
0.000001	Colloidal particles	283290 m^2	63 yr minimum

SOURCE: (Powell S.T., 1954).

The process of coagulation may also find use, although not always, in the softening of hard water. Softening is more properly a precipitation process, and coagulation is used to obtain a more rapid and complete settling of the precipitated hardness components.

2.7 COAGULATION CONTROL STRATEGIES

Many variables affect the destabilization process of coagulation and the physical and chemical properties of the agglomerated particles that are produced. The optimum dosage of coagulants for a specific water are easily and effectively determined using the simple jar test (the jar test simulates the batch test).

The jar test may be used for the following: (a) coagulant selection, (b) dosage selection, (c) coagulant aid selection and its dosage selection, (d) determination of optimum pH, (e) determination of point of addition of pH adjustment chemicals and coagulant aids, (f) optimization of mixing energy and time for rapid mixing and slow mixing and (g) determination of dilution of coagulant and other similar measurements.

A typical jar test optimizing the dosage of coagulant includes the following steps: (a) While rapidly mixing the water, add different dosages of coagulant to six jars that contain water from the same source. Multiple syringes can be used to inject the coagulant quickly into each jar near the impeller. (b) Continue to rapidly mix the coagulant for 0.5 to 1.0 min at the maximum mixing intensity possible [commonly 100 revolutions per minute (rpm)]. (c) Slowly mix the suspensions at 25 to 35 rpm for 15 to 20 min. (d) Allow the floc to settle for 30 to 45 min without stirring. (e) Measure the turbidity of the settled water by pipetting samples of the settled water from just below the surface of water in jars or alternatively, by drawing samples from a port located at a fixed distance below the surface. Also, samples can be taken from the port at different times to obtain a settling velocity versus turbidity curve. The lowest residual turbidity corresponds to the optimum coagulant dose. The rotational speed of the stirrer in revolutions per minute can be calibrated to the average velocity gradient in the jar, and hence the jar test may be used to evaluate different mixing energies for rapid mixing and slow mixing. In addition to residual turbidity in jar tests other parameters such as zeta potential, streaming current, and particles size analysis may be used to supplement the data from jar test as strategies for coagulation control.

2.8 COAGULATION OF COLOUR

2.8.1 OCCURRENCE AND NATURE OF COLOUR

Colour, in addition to turbidity, is a common constituent of some surface waters and must be reduced by the water plant. Although colloidal forms of iron and manganese are sometimes the cause of colour in water and although industrial waste discharge can cause discoloration of water, the most common cause is complex organic compounds originating from the decomposition of natural organic matter.

There have been numerous and continuing attempts to chemically define the nature of colour in water. This goal has not yet been attained, and disagreement still exists among investigators as to certain aspects of the fundamental nature of colour. It is generally agreed, however, that the organic compounds producing colour in water are derived mainly from soil humus which, in turn, is produced by the decay of vegetation. Colour comprises a broad category of organic compounds, which are collectively termed "humic substances", which simply denotes a group of compounds having similar properties.

2.8.2 COLOUR COAGULATION

Several characteristics of the removal of colour by coagulation indicate that the mechanism is entirely different from that for the removal of turbidity. Whereas clay turbidity is best removed with a pH range of about 6.5 to 7.5, colour removal is generally obtained at acid pH's of about 4 to 6. The dosage of coagulant is closely dependent on the initial concentration of colour, in contrast to only slightly increased coagulant required for increasing concentration of turbidity. It is also significant that zeta potential (always measured and frequently expressed as electrophoretic mobility) is closely correlated with residual colour concentration. At the optimum pH, residual colour decreases proportionately with increase in coagulant dose.

2.8.3 MECHANISM OF COLOUR REMOVAL

The mechanism of removal of colour can more properly be regarded as a process of chemical precipitation rather than coagulation. This significant difference is due entirely to the inherent difference between particles causing turbidity and those responsible for colour. The charge on the hydrophilic colour particles is due to ionogenic chemical groups which are an integral part of the compounds. These groups, such as carboxyl, hydroxyl, and others, determine the charge on the particle, and the charge depends on the degree of ionization, which in turn is influenced by the pH of the water. There is strong evidence that a chemical interaction occurs between the partially hydrolyzed iron or aluminium coagulant and some acidic group on the colour molecule, forming an insoluble basic salt. The insolubility of the basic salt causes a precipitation, removing from solution both the colour and coagulant compounds. The slight solubility of certain salts of coloured compounds and coagulants is frequently responsible for some of the colour remaining even after optimum conditions are obtained for its removal.

2.9 INDICATORS OF WATER QUALITY

The indicators of water quality are generally categorized into physico-chemical and biological factors.

2.9.1 PHYSICO-CHEMICAL PARAMETERS

Some of the Physico-chemical parameters of interest are:

2.9.2 pH

The pH of a solution is a measure of the acidic or basic nature of that solution. The concentration of the hydrogen ion $[H^+]$ activity in a solution determines the pH.

Mathematically this is expressed as

$$pH = -\log [H^+]$$

Pure water at 25°C contains equal amount of hydroxyl and hydroxonium ions. Natural waters often have a pH of 4 to 9 and most are slightly basic as a result of the presence of bicarbonates and carbonates of the alkali and alkaline earth metals.

Principle: The determination of pH involves the activity of hydrogen ions by potentiometric measurement using a standard electrode and a reference electrode. The hydrogen electrode consists of a platinum electrode across which hydrogen gas is bubbled at a pressure of 101 Kp_A. Due to the difficulty in the use of this method, the glass electrode is usually used in pH measurements. The pH meter is normally calibrated potentiometrically with an indicator glass electrode using buffers. Measurements of pH are influenced by temperature in two ways: mechanical effects caused by changes in the properties of the electrode and chemical effects caused by equilibrium changes [APHA, 1998].

2.9.3 HARDNESS

The hardness of a water supply is determined by the content of calcium and magnesium salts. Calcium and magnesium combine with bicarbonates, sulphates, chlorides and nitrates to form their salts. The standard domestic measurement for hardness is grains per gallon (gpg) as $CaCO_3$. Water having a hardness content less than 0.6 gpg is considered commercially soft. The calcium and magnesium salts which form hardness are divided into two categories: temporary hardness (containing carbonates) and permanent hardness (containing non-carbonates).

Principle: Ethylenediaminetetraacetic acid (EDTA) and its sodium salt form a chelate soluble complex in solution of certain metal ions. The addition of small amounts of dye such as Erichrome Black-T or calmagite to an aqueous solution containing calcium and magnesium at pH = 10±1 will result in a red wine coloured solution indicating the end point. When EDTA is used as the titrant, calcium and magnesium ions will be complexed and the red wine colour appears after all such ions have been complexed. Magnesium ion must be present to yield a satisfactory end point.

2.9.4 ALKALINITY

Alkalinity may be defined as the ability of water to neutralize an acid, and is determined by titration against a known standard acid (usually 0.02 N sulphuric acids). Alkalinity has traditionally been reported in terms of mg/l as $CaCO_3$. The optimal amount of alkalinity for a given water is a function of several factors including pH, hardness and the concentrations of dissolved oxygen and carbon dioxide that may be present. As a general rule, 30 to 100 mg/l as $CaCO_3$ is desirable although up to 500 mg/l may be acceptable [APHA, 1998].

Alkalinity is apparently unrelated to public health (at least directly), but is very important in pH control. Alum, gaseous chlorine and other chemicals occasionally used in water treatment act as acids and therefore tend to depress pH. Alkalinity resists this change and thereby provides buffer capacity. Many waters are deficient in natural alkalinity and must be supplemented with lime [CaO or $Ca(OH)_2$] or some other chemical to maintain the pH in the desirable range (usually 6.5 to 8.5).

Alkalinity values can change significantly for groundwater between samples taken at wellhead and samples taken from other spots [USEPA, 1999].

Principle (Titration Method): Alkalinity is generally expressed as phenolphthalein alkalinity corresponding to titration with acid to the pH at which HCO_3^- is the predominant carbonate species (pH 8.3) or total alkalinity, corresponding to titration with acid to the methyl orange end point (pH 4.3) where both carbonate species have been converted to CO_2. Alkalinity is generally expressed in mg/l of $CaCO_3$ based upon the following neutralizing reaction.

$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$

Each CO_3^{2-} ion neutralises two $2H^+$ ions [APHA, 1998].

2.9.5 COLOUR

Colour in water is almost always due to organic material which is usually extracted from decaying vegetation. Colour is common in surface water supplies, while it is virtually non-existent in spring water and deep wells. Colour in water may also be the result of natural metallic ions (iron and manganese). A yellow tint to the water indicates that humic acids are present, referred to as "tannins". A reddish colour would indicate the presence of precipitated iron. Dark brown to black stains are created by manganese. Excess copper can create blue stains [APHA, 1992].

Principle: The observed colour of water is the result of light back scattered upward from the water after it has passed through to various depths and undergone selective absorption. Colour and turbidity determine the depth to which light penetrates in water systems. In water, the light intensity or irradiance at a particular depth (I_z) is a function of the depth distance z which is called the Beer-Lambert's Law, $I_z = I_o e^{-nz}$ [APHA, 1998]. In pure water, light is highly absorbed in the infrared region of the light spectrum and poorly absorbed in the blue region. Extinction coefficients are influenced by water absorption, suspended organic and inorganic particles and dissolved compounds. Thus the visible colour in a water sample is the light that is refracted, reflected or reemitted by substances in water because it has not been absorbed to produce heat or chemical reactions.

True colour is due to natural minerals such as ferric hydroxide and dissolved organic substance such as humic or fulvic acids. Colour measured in water containing suspended matter is defined as apparent colour [APHA, 1992].

Standard measured comparisons can be made with sealed containers. Natural waters range from <5 mg/l in very clear water to 1200 mg/l in dark peaty waters. As some of the compounds determining the colour of water are not very stable, measurements should be made within two hours of collection. Colour can also be measured by visual comparison with colour discs. This method is what was employed for this work [APHA, 1998].

2.9.6 TURBIDITY

The cloudiness of waters is referred to as turbidity and has its origin from particles suspended in the water. It is found in most surface water, but usually doesn't exist in groundwater except in shallow wells or springs after heavy rains. Turbidity gives the water a cloudy appearance or shows up as dirty sediment. Undissolved materials such as sand, clay, silt or suspended iron contribute to turbidity. Turbidity can cause the staining of sinks and fixtures as well as the discolouring of fabrics. Usually turbidity is measured in NTUs (nephelometric turbidity units). Typical drinking water will have a turbidity level of 0 to 1 NTU [APHA, 1998].

Principle: Turbidity of water is caused by suspended matter such as clay, silts, finely divided organic and inorganic matter, soluble coloured organic compounds and plankton and other microscopic organisms. Turbidity expresses the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the samples. Correlation of turbidity with weight concentration of suspended matter is difficult because the size, shape and refractive index of the particulates also affect the light scattering properties of the suspension [APHA, 1998].

2.10 APPLICATION OF INDIGENOUS MATERIALS IN WATER TREATMENT

2.10.1 INTRODUCTION

Natural materials have been used in water treatment since ancient times but lack of knowledge on the exact nature and mechanism by which they work has hindered their wide spread application. As a result, they have been unable to compete with the commonly used chemicals. In recent years there has been a resurgence of interest to use natural materials due to cost and associated health and environmental concerns of synthetic organic polymers and inorganic chemicals.

2.10.2 NATURAL COAGULANTS

A number of effective coagulants have been identified of plant origin. Some of the common ones include nirmali (Tripathi et al., 1976), *M. oleifera* (Oslen, 1987; Jahn, 1988), okra (Al Samawi and Shorkrala, 1996), Cactus latifaira and Prosopis juliflora (Diaz et al., 1999), tannin from valonia (Özacar and Sengil, 2000), apricot, peach kernel and beans (Jahn, 2001), and maize (Raghuwanshi et al., 2002). Bhole (1995) compared 10 natural coagulants from plant seeds. The study indicated that maize and rice had good coagulation effects when used as primary coagulants or coagulant aid. Chitosan, a natural coagulant from animal origin is also an effective coagulant (Pan et al., 1999; Davikaran & Pillai, 2001; Guibal et al., 2006). It has unique properties among biopolymers, especially due to the presence of primary amino groups. It is a high molecular weight polyelectrolyte derived from deacetylated chitin and it has characteristics of both coagulants and flocculants: high cationic charge density, long polymer chains, bridging of aggregates, and precipitation (in neutral or alkaline pH conditions). It has also been used for the chelating of metal ions in near-neutral solution and the complexation of anions in acidic solution (cationic properties due to amine protonation). Its coagulation and flocculation properties can be used to treat particulate suspensions (organic or inorganic) and also to treat dissolved organic materials. It has also been reported that chitosan possesses antimicrobial properties (Liu et al., 2000; Chung et al., 2003). By using natural coagulants, considerable savings in chemicals and sludge handling cost may be achieved. Al-Samawi and Shokrala (1996) reported that 50-90% of alum requirement could be saved when okra was used as a primary coagulant or coagulant aid.

Apart from being less expensive, natural coagulants produce readily biodegradable and less voluminous sludge. For example, sludge produced from *M. oleifera*- coagulated-turbid water is only 20-30% of that of alum treated water (Ndabigengesere et al., 1995; Narasiah et al., 1995). The coagulation process in water treatment is complimented by filtration. The successfulness of coagulation in most cases determines the performance of the filtration system, which may be of a mono medium or dual media type. Of all the plant materials that have been investigated over the years, the seeds from *M. oleifera* have been shown to be one of the most effective as a primary coagulant for water treatment.

2.11 MORINGA OLEIFERA IN WATER TREATMENT

2.11.1 GENERAL

The use of natural materials of plant origin to clarify turbid surface waters is not a new idea. Sanskrit writings in India dating from several centuries BC make reference to seeds of the tree *Strychnos potatorum* as a clarifier. Peruvian texts from the 16th and 17th centuries detail the use by sailors of powdered, roasted grains of *Zea mays* as a means of settling impurities. More recently, Chilean folklore texts from 19th century refer to water clarification using the sap from the 'tuna' cactus (Opuntia fiscus indica). However, of all the plant materials that have been investigated over the years, the seeds from *Moringa oleifera* have been shown to be one of the most effective as a primary coagulant for water treatment (Jahn and Dirar, 1979).

The traditional use of the *Moringa oleifera* seeds for domestic household water treatment has been limited to certain rural areas in the Sudan. Village women collecting their water from River Nile would place powdered seeds in a small cloth bag to which a thread is attached. This would then be swirled around in the turbid water. Water soluble proteins released from the powdered seeds, attach themselves to, and bind between, the suspended particles forming larger, agglomerated solids. These flocculated solids would then be allowed to settle prior to boiling and subsequent consumption of the water (Jahn, 1986).

Moringa oleifera belongs to the family Moringaceae which is a single genus family of shrubs and trees cultivated across the whole of the tropical belt and used for a variety of purposes (Jahn, 1986). The dry seed suspension is known to be a natural coagulant and coagulant aid (Jahn, 1979-1986; Folkard et al., 1989-1994; Sani, 1990 Bina, 1991).

Moringa oleifera has a variety of English and multitude of local vernacular names which illustrate the many uses to which this tree and its products have been put. In some places is it known as the 'drumstick' tree because of the shape of its pods which are a major food product in India and Africa. It is also known as the 'horseradish' tree because of the taste of its roots, which the British in India often used as a substitute for horseradish (Folkard and Sutherland, 1994). Various vernacular terms for the tree associated with Africa include (Jahn, 1986):

Nigeria	-	Adagba makero
Burkina Faso	-	Aryentiga / La–Banyu
Malawi	-	Chainwamba/Kangaluni / Sangoa
Ghana	-	Yevutsi (Ewe)
Kenya	-	Mborongi
Tanzania	-	Mlonga / Mronge
Gambia	-	Neberdaya

2.11.2 BOTANY

The *Moringa oleifera* is a small, fast growing, drought resistant deciduous tree that ranges in height from 5-12 m with an open, umbrella shaped crown, straight trunk (10-30 cm thick) with corky, whitish bark. The evergreen foliage (depending on climate) has leaflets 1-2 cm in diameter; the flowers are white or cream coloured. The fruits (pods) are initially light green, slim and tender, eventually becoming dark green, firm and up to 120 cm long, depending on the variety. Fully mature, dried seeds are round or triangular shaped, the kernel being surrounded by a lightly wooded shell with three papery wings. It tends to be deeply rooted, has a wide open typically-umbrella shaped crown and usually a single stem (Schwarz Dishna, 2000).

2.11.3 HOW MORINGA SEEDS WORK

Natural coagulant properties were found in 6 different Moringa species by laboratory studies (Schwarz Dishna, 2000). The seed kernels of *Moringa oleifera* contain significant quantities of low molecular-weight, water-soluble proteins which carry a positive charge. When the crushed seeds are added to raw water, the proteins produce charges acting like magnets and attracting the predominantly negatively charged particles (such as clay, silk, bacteria and other toxic particles) in water. The flocculation process occurs when the proteins bind the negative-charge-forming flocs through the aggregation of particles which are present in water. These flocs are easily removed by settling or filtration. The material can clarify not only highly turbid muddy water but also water of medium and low turbidity.

The level of turbidity influences the required time for the flocculation. As with all coagulants, the effectiveness of the seeds may vary from one raw water to another. The practical application of dosing solutions is exactly the same as for all other coagulants. Studies have been carried out to determine the potential risks associated with the use of Moringa seeds in water treatment. To date, no evidence has been found that the seeds cause secondary effects in humans, especially at the low doses required for water treatment.

2.11.4 WATER TREATMENT

Solutions of Moringa seeds for water treatment may be prepared from seed kernels or from the solid residue left over after oil extraction (press cake). Moringa seeds, seed kernels or dried press cake can be stored for long periods but Moringa solutions for treating water should be prepared fresh each time. In general, 1 seed kernel will treat 1 liter of water.

Dosage Rates:	Low turbidity	NTU< 50	1 seed per 4 litres water
	Medium turbidity	NTU 50-150	1 seed per 2 litres water
	High turbidity	NTU 150-250	1 seed per 1 litre water
	Extreme turbidity	NTU> 250	2 seeds per 1 litre water

SOURCE: (Doerr Beth, 2005).

2.11.5 STEPS FOR HOUSEHOLD WATER TREATMENT

The following steps can be applied in a household in using *Moringa oleifera* for water clarification.

1. Collect mature *Moringa oleifera* seed pods and remove seeds from pods.
2. Shell seeds (remove seed coat) to obtain clean seed kernels; discard discoloured seeds.
3. Determine quantity of kernels needed based on amount and turbidity of water; in general 1 seed kernel will treat 1 liter of water.
4. Crush appropriate number of seed kernels (using grinder, mortar & pestle, etc) to obtain a fine powder and sift the powder through a screen or small mesh.
5. Mix the seed with 250 ml (1 cup) of clean water into a bottle and shake for 1 minute to activate the coagulant properties and form a solution.

6. Filter this solution through a muslin cloth or fine mesh screen (to remove insoluble materials) into the water to be treated
7. Stir treated water rapidly for at least 1 minute then slowly (15-20 rotations per minute) for 5-10 minutes.
8. Let the treated water sit without disturbance for at least 1-2 hours.
9. When the particle and contaminants have settled to the bottom, the clean water can be carefully poured off.
10. This clean water can then be filtered or sterilized to make it completely safe for drinking (Doerr Beth, 2005).

2.11.6 HOW MORINGA GROWS

2.11.6.1 RAINFALL AND ALTITUDE

Moringa requires an annual rainfall of between 250 and 3000 mm. It is drought resistant, though in drought conditions it may lose its leaves. This does not mean it is dead and it should recover when the rains arrive. It grows best at altitudes up to 600 m but it will grow at altitudes of 1000 m.

2.11.6.2 TEMPERATURE

It will survive in a temperature range of 25°C to 40°C but has been known to tolerate temperatures of 48°C and light frosts.

2.11.6.3 SOIL

Moringa prefers neutral to slightly acidic soil and grows best in well-drained loam to clay-loam. It tolerates clay soils but does not grow well if waterlogged (Schwarz Dishna, 2000).

2.11.7 USES OF MORINGA OLEIFERA

All of the parts of the tree can be used in a variety of ways. Moringa is full of nutrients and vitamins and is good for food as well as in the food of animals. Moringa helps to clean dirty water and is a useful source of medicines. It provides lots of leafy material that is useful when using alley cropping systems. There are many other uses and these are discussed below:

2.11.7.1 HUMAN FOOD

All Moringa food products have a very high nutritional value. One can eat the leaves, especially young shoots, young pods, flowers, roots, and in some species even the bark. Leaves are low in fats and carbohydrates and rich in minerals, iron and vitamin B. It is particularly useful as human food because the leaves appear towards the end of the dry season when few other sources of green leafy vegetables are unavailable (Schwarz Dishna, 2000).

2.11.7.2 ANIMAL FODDER

Cattle, sheep, pigs, goats and poultry browse the bark, leaves and young shoots of Moringa. The best diet for pigs is 70% Moringa, 10% Leucaena and 20% other leaves. It is possible for their diet to be 100% Moringa but it should be no more than 30% Leucaena. The pork from pigs fed on this diet is lean. If trees are intended for animal fodder it is useful to prune them to 4 m high, but if they are not they should be pruned to 6 m so harvesting for human consumption can be easily carried out (Schwarz Dishna, 2000).

2.11.7.3 NATURAL MEDICINES

Around the world every part of the Moringa tree has been used effectively against varying ailments. Some of the remedies are described here but there is no guarantee they will work for every case (Schwarz Dishna, 2000).

2.11.7.4 FERTILISER

The seed cake, which is produced by pressing the seeds to extract oil, cannot be eaten as it contains harmful substances. However, it contains high levels of protein and makes a good fertilizer for use in agriculture (Schwarz Dishna, 2000).

2.11.7.5 LIVING FENCE

Planted as a living fence, Moringa provides wind protection and shade. It grows very quickly and if cuttings are planted close together they will form a fence that livestock cannot get through in just 3 months (Schwarz Dishna, 2000).

2.11.7.6 ALLEY CROPPING

Moringa has a large tap root and few lateral roots so it will not compete for nutrients with the crops. It will also add to the nutrients available as it produces many protein rich leaves. They grow very quickly but do not provide too much shade due to the structure of their leaves. They are also very good at reclaiming marginal land (Schwarz Dishna, 2000).

2.11.7.7 FUELWOOD AND OTHER USES

The wood is light and is a good fuel for cooking. However, it is not suitable for building. The bark can be beaten into a fibre that can be used to make rope or mats and the wood produces a blue dye. Chippings of wood can be used to make a good quality paper. The tree also produces viscose resin that is used in the textile industry.

2.11.8 HOW TO PROPAGATE MORINGA

2.11.8.1 GROWING FROM SEED

Seeds can be planted as soon as they are mature but should only be kept for up to 3 months in natural conditions. Before sowing, soak the seeds in water for one day then plant the seeds 2 cm apart and 1cm deep. Water lightly and they will germinate in 15 days. When the seedlings reach 30 cm in height they should be thinned to 10 cm apart and when they reach 60 to 90 cm tall they can be planted out, but they will be very fragile (Schwarz Dishna, 2000).

2.11.8.2 GROWING FROM CUTTINGS

Cuttings of healthy branches with hard wood, 45 cm to 1.5 m long and 10 cm wide, should be taken in the rainy season. Trim any green wood without damaging the bark of the hardwood and leave the cutting ends in a shady place for 3 days to dry. Plant the cutting directly in the soil. One third of the cutting's length should be placed in the soil (i.e. if the cutting is 1.5 m long, plant it 50 cm deep). The soil should be moist but not over-watered (Schwarz Dishna, 2000).

2.11.8.3 PRODUCTION RATES

Within 3 years of planting one tree will produce 300 to 400 pods every year and a mature tree can produce up to 1000 pods. Frequent pruning of the growth tips will maintain and increase leaf growth and the height can be controlled to make harvesting easier (Schwarz Dishna, 2000).

2.11.9 PREVIOUS STUDIES

Recently, *Moringa oleifera* has been explored as a potential agent to soften hard water. Muyibi and Evison (1995) performed a series of jar tests on water from two groundwater sources, one surface water source and synthetic water (distilled water spiked with calcium chloride). The water hardness ranged from 300 to 1000 mg/l as $CaCO_3$. Experimental results showed that the hardness removal efficiency increased with Moringa dose. They also found that a higher coagulant dose was required when the concentration of hardness-causing species in solution increased. These results were confirmed by Muyibi and Okufu (1995) during experiments on 17 groundwater sources. The authors of both studies suggest removal of hardness ions by a combination of absorption, which is approximated by a Langmuir isotherm and by precipitation of the hardness-causing ions. Sani (1990) carried out jar tests with *Moringa oleifera* as the primary coagulant using water from four different sources (viz two surface and two shallow wells) with turbidities from 100 to 800 NTU and 80 to 150 NTU respectively and hardness from 180 to 300 mg/l as $CaCO_3$. It was observed that in addition to turbidity reduction of 92 to 99%, the hardness was also reduced to between 60 to 70% after coagulation and two hours settling.

Ndabigengesere and Narasiah (1998) experimented with *Moringa oleifera* seeds as a primary coagulant for the treatment of industrial and municipal wastewater. Extracts from pulverized Moringa seeds efficiently reduced the suspended solids, microorganisms and some heavy metals, but increased the chemical oxygen demand, nitrogen and phosphorus concentrations of the wastewaters.

Al-Khalili et al., (1997) found low doses of *Moringa oleifera* extract to be effective in contact flocculation filters for low turbidity waters. Experiments were performed with laboratory sand contact flocculation filters at filtration rates of 10 and 20 m/hr and raw water turbidities from 10 to 75 NTU. Experiments showed that the natural coagulant was effective on low turbidity water at filtration rates at or below 10 m/hr.

Jahn conducted a series of studies into the coagulative properties of *Moringa oleifera*. She produced simple methods for protein extraction and guidelines for estimating required dose for household use based on cloudiness of the raw water. An appropriate number of seeds were crushed and placed in a cloth sack that was swirled in the turbid water for 5 to 10 minutes. Laboratory experiments indicated that in addition to dramatic turbidity reduction, total bacteria counts were initially reduced after coagulation with *Moringa oleifera* seeds (Jahn and Dirar, 1979). Similarly, Olsen (1987) showed reduction in the cercariae of schistosoma mansoni, a pathogenic helminth responsible for the occurrence of schistomiasis in humans, after coagulation with *Moringa oleifera* seeds. Jahn's initial work set the foundation for the subsequent research that has been accomplished over the past 25 years.

Ndabigengesere and Narasiah have completed much of the analytical research on coagulation with *Moringa oleifera* proteins. They confirmed the activity of *Moringa oleifera* seeds in removing kaolin turbidity from synthetic water (distilled water spiked with calcium chloride) and tested various parts of both the green and dried seed pods including the whole pods, bark of the seeds, as well as both shelled and unshelled green dried seeds. Coagulation activity was present only in filtered and unfiltered extracts from shelled and unshelled dried seeds (Ndabigengesere et al., 1995).

Water quality parameters important in the drinking water field were measured by Ndabigengesere and Narasiah (1998) for water treatment with *Moringa oleifera* extract as well as water treated with alum. Several lumped characteristics of the finished water were measured, including pH, conductivity, alkalinity, sludge volume, hardness, absorbance at 280 nm, and chemical oxygen demand (COD), in addition to some specific ions, including orthophosphate, nitrate, sulphate and chloride concentrations. Experiments were performed on extracts produced from both shelled and non-shelled *Moringa oleifera* seeds. Results indicated that coagulation with *Moringa oleifera* did not affect the pH of the water, did not consume alkalinity nor change the conductivity, did not increase the total ions in solution except for an increase in orthophosphates and nitrates and produced a sludge volume that was approximately one-sixth the sludge volume produced with alum coagulation. When compared to alum, coagulation with *Moringa oleifera* seeds does not require pH control, nor would it be likely to result in corrosion problems in a distribution network. The major disadvantages of full-scale treatment with *Moringa oleifera* crude-water extract are the elevated nitrate and orthophosphate concentrations and increase in chemical oxygen demands.

In 1993, a group of researchers conducted pilot scale treatment trials and a 6-hour full scale *Moringa oleifera* test on the public water treatment plant in Thyolo, Malawi (Sutherland et al., 1994). The pilot scale tests indicated that seed doses between 75 and 250 mg/l were required to achieve 90% turbidity reductions in natural water with an initial turbidity of 400 NTU. The flow rate through the pilot plant was 1 m^3/hr. At flow rates in the full-scale plant of 16 m^3/hr, turbidity reductions observed in experiments using both alum and Moringa were similar, but in both cases significant floc carryover from the clarifier to the filter was observed. The researchers concluded that Moringa acted as a viable alternative to alum in the treatment plant conversion to Moringa.

Jahn and Dirar (1979) reported that the chemical makeup of *Moringa oleifera* seeds is 4% moisture, 20-40% crude protein, 34% oil, 16.4% nitrogen-free extract, 3.5% fiber and 3.2% ash. Gassenchmdt et al (1995) sequenced the amino acids present in the protein powder extracted by defatting the pulverized seed with trichlorofluoromethane, and then separating the charged species by ion exchange chromatography. They found two active fractions of molecular mass 6.5 and 7 kilodaltons (kDa). Amino acid sequencing showed a total of 60 residues and high concentrations of glutamine, arginine and proline. Comparison with the European Molecular Biological Laboratory data bank found no significant sequence homologies with previously sequenced proteins. Based on the small size of the proteins, it was suggested that destabilization probably occurs through adsorption and charge neutralization. Contrarily, Muyibi and Evison (1995) suggested that the mechanism for particle restabilization is adsorption and interparticle bridging because of destabilization at high doses. They do not acknowledge that particle destabilization also occurs in charge neutralization.

Studies by Eilert et al., (1981) identified the presence of an active antimicrobial agent in *Moringa oleifera* seeds. The active agent isolated was found to be 4α-L-rharmnosyloxy-benzyl isothiocyanate. Madsen et al., (1987) carried out coagulation and bacteria reduction studies on turbid Nile water in the Sudan using *Moringa oleifera* seeds and observed turbidity reduction of 80 to 99.5% paralleled by bacteria reduction of (90 to 99.99%) within the first one to two hours of treatment, the bacteria being concentrated in the coagulant sediment. Also studies by Talbot, Brian et al (1995) have shown that *Moringa oleifera* as a coagulant is non-toxic and biodegradable.

The seeds have shown reduced effectiveness at low turbidities for some raw water. Although floc formation is evident, the flocs formed are small, compact and light resulting in significantly reduced settling velocities. This is considered to be a function of the mechanism of coagulation and flocculation involved. The low molecular weight of the active proteins indicates that charge neutralization and floc formation are brought about by the patch mechanism as opposed to the bridging mechanism (Gregory, 1991). Also, there is an increased turbidity removal for water samples with high initial turbidities because of increase in particle collision frequency and agglomeration rate (Lamer and Healy, 1963; Birkner and Morgan, 1968).

3 MATERIALS AND METHODS

3.1 EXPERIMENTAL DESIGN

All the jar tests and physico-chemical analyses were performed in the Barekese Water Headwork Laboratory of the Ghana Water Company Limited. The source of water was also from the Barekese dam. All the sample water was temporarily stored in a plastic container. Water was collected during dry (7[th] January, 2008) and wet season (5[th] May, 2008). The water in the dam had a low natural turbidity during the months when this study was carried out (January and May), and for most test series the water had to be spiked with artificial turbidity. This was done using ordinary clay. The clay was first ground with a mortar to make the particles as fine as possible, and then added to the water in sufficient amounts to produce the desired turbidity. The following parameters were determined: pH, Colour, Turbidity, Suspended Solid, Hardness, and Alkalinity.

3.2 CHEMICALS AND EQUIPMENT

- Hydrochloric Acid by BDH Laboratory Supplies, Britain
- Concentrated Ammonia Solution by BDH Laboratory supplies, Britain
- Erichrome Black T by BDH Laboratory supplies, Britain
- Methyl orange indicator by Fisons Laboratory
- Phenolphthalein indicator by Fisons Laboratory
- Disodium salt of Ethylenediaminetetraacetic acid (EDTA) by BDH Laboratory supplies, Britain
- Plastic containers
- Refrigerator
- Mettler Toledo pH meter
- HACH DR/2000 Direct Reading Spectrometer

- Sibata flocculator
- Weighing balance
- Beakers
- Filter papers
- Measuring cylinders
- Colour comparator

3.3 MEASUREMENT OF QUALITY PARAMETERS OF WATER SAMPLES

3.3.1 pH DETERMINATION

Mettler Toledo pH meter was used to measure the pH.

Calibration of pH meter

The pH meter was calibrated with 4.0 and 7.0 pH buffer solutions prior to the start of the experiments.

Method

A 100 ml of each of the six water samples was measured into a beaker and the pH determined using the pH meter. This was repeated three times and the mean value taken.

3.3.2 SUSPENDED SOLIDS DETERMINATION

HACH DR/2000 Direct Reading Spectrometer was used to determine the suspended solids.

Method

A test tube was filled with distilled water to the 25 ml mark and this served as the blank. The blank was inserted into the spectrometer and then zeroed. The test tube was then filled to the 25 ml mark with water from each of the six beakers. This was inserted in the *HACH DR*/2000 direct reading spectrometer. The suspended solids reading in (mg/l) was recorded when the reading stabilized.

3.3.3 TOTAL HARDNESS DETERMINATION

Indicator: Erichrome Black T

Buffer: Concentrated Ammonia Solution

Disodium salt of Ethylenediaminetetraacetic acid (EDTA)

Method

A 50 ml sample of water was measured into a conical flask. To this, was added a portion of ammonium buffer solution which was then followed by the addition of Erichrome Black T indicator. The resulting solution was titrated with EDTA solution with continuous stirring until the end point was reached. That is when the colour changes from purple to blue.

3.3.4 ALKALINITY DETERMINATION

Indicator: Methyl orange

Method

A 50 ml sample of water was measured into a conical flask. Two drops of methyl orange indicator was added and the resulting mixture titrated against the standard HCL solution till the end point was reached. That is when the colour changes from yellow to orange.

3.3.5 COLOUR DETERMINATION

HACH DR/2000 Direct Reading Spectrometer was used to determine the colour.

Method

A test tube was filled with distilled water to the 25 ml mark and this served as the blank. The blank was inserted into the spectrometer and then zeroed. The test tube was then filled to the 25 ml mark with water from each of the six beakers. This was inserted in the *HACH DR*/2000 direct reading spectrometer. The colour reading in haxen units (HU) was recorded when the reading stabilized. The result obtained was then confirmed with the colour comparator. This was done by visual comparison on a colour disc. 50 ml of sample was measured into a special test tube used for colour analysis. The colour disc was rotated until a standard colour match was found for the samples.

3.3.6 TURBIDITY DETERMINATION

HACH DR/2000 Direct Reading Spectrometer was used to determine the turbidity.

Method

A test tube was filled with distilled water to the 25 ml mark and this served as the blank. The blank was inserted into the spectrometer and then zeroed. The test tube was then filled to the 25 ml mark with water from each of the six beakers. This was inserted in the *HACH DR*/2000 direct reading spectrometer. The turbidity reading in (NTU) was recorded when the reading stabilized.

3.4 DETERMINATION OF WEIGHT OF SLUDGE PRODUCED

At the end of settling of flocs, the water in each beaker was decanted and the sludge left behind was filtered, dried in an oven at 110°C for 10 hours, allowed to cool in a desiccator for 24 hours and then weighed.

3.5 PREPARATION OF *MORINGA OLEIFERA* CONCENTRATION

Dry *Moringa oleifera* seeds used for the studies were obtained from Bolgatanga in the Upper East of Ghana and Presbyterian Church farm at Dansoman, Accra. Good quality *Moringa oleifera* seeds were selected and the seed wings and coat removed. Half a kilogramme of the kernel was ground to a fine powder using a blender (Moulimex) followed by pestle and mortar. The powder obtained was then sieved through a sieve of mesh size 425 µm to achieve solubilization of active ingredients in the seed.

The seed powder was mixed with a small amount of clean water to form a paste. The paste was then diluted to the required strength before using it. Dosing solutions were prepared from 1% to 10% concentration, i.e. 1 to 10 gram of Moringa in 100 ml of distill water.). This was then stirred for 2 minutes to extract the active ingredient. Insoluble material was filtered out using white cotton cloth. Fresh solution was prepared for use as and when needed since according to Jahn (1986), deterioration sets in after 2 days storage at room temperature.

3.6 OPTIMIZATION OF *MORINGA OLEIFERA* DOSAGE AND TIME

1000 ml of water samples were placed in six one-liter beakers and the stirrers of the jar test apparatus (*Sibata Flocculator*) inserted. Different dosages of 5.5 ml, 6.0 ml, 6.5 ml, 7.0 ml, 7.5 ml, 8.0 ml of 1% to 10% (1 – 10 gram of Moringa in 100 ml of distill water) of the prepared *Moringa oleifera* suspension was added to each of the six one liter beakers and the contents of the beakers stirred for 1 minute at a speed of 180 rpm. The speed of mixing was reduced to 50 rpm and slow mixing carried out for 15 minutes for flocculation. The turbidity, colour, suspended solids and pH of the supernatant water from each of the six beakers were determined for 1, 2 and 3 hours settling time. The alkalinity and hardness of the settled water were also determined.

3.7 ALUM DOSAGE

1000 ml of water samples were placed in six one-liter beakers and the stirrers of jar test apparatus (*Sibata Flocculator*) inserted. Different dosages of 5.5 ml, 6.0 ml, 6.5 ml, 7.0 ml, 7.5 ml, 8.0 ml of 1% alum (1 gram of alum in 100 ml of distill water) was added to each of the six one liter beakers and the contents of the beakers stirred for 1 minute at a speed of 180 rpm. The speed of mixing was reduced to 50 rpm and slow mixing carried out for 15 minutes for flocculation. The turbidity, colour, suspended solids, pH, alkalinity and hardness of the supernatant water from each of the six beakers were also determined after 1 hour settling time.

4 RESULTS AND DISCUSSION

4.1 DETERMINATION OF OPTIMUM TIME FOR THE APPLICATION OF *MORINGA OLEIFERA* ON WATER

Figures 4.1(a) to 4.1(f) show the change in colour of Moringa–treated water for settling times of 1, 2 and 3 hours against varying Moringa concentrations with initial turbidity of 40 NTU (Dry season) at dosages of 5.5, 6.0, 6.5, 7.0, 7.5 and 8.0 ml.

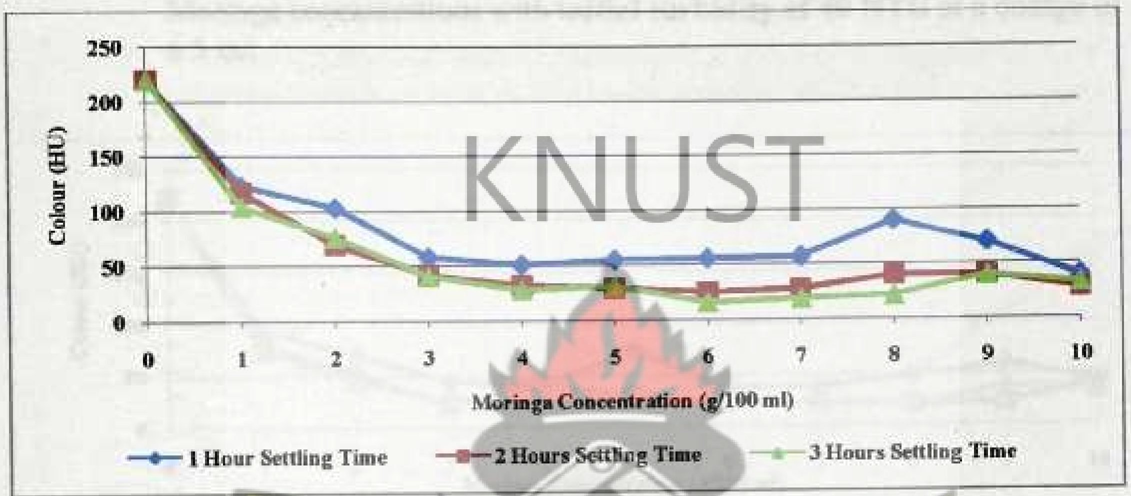

Fig. 4.1(a): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 5.5 ml.

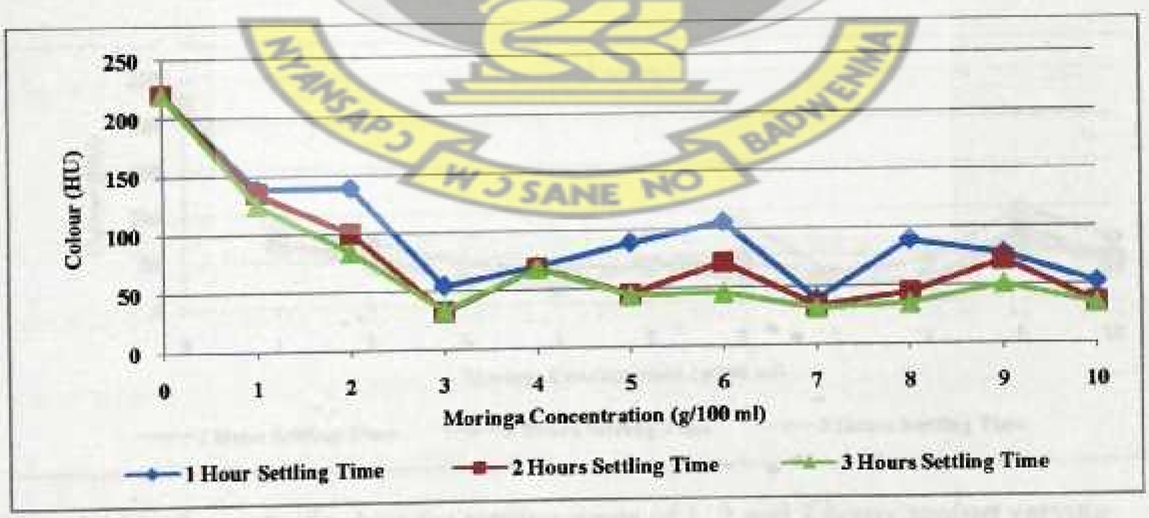

Fig. 4.1(b): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 6.0 ml.

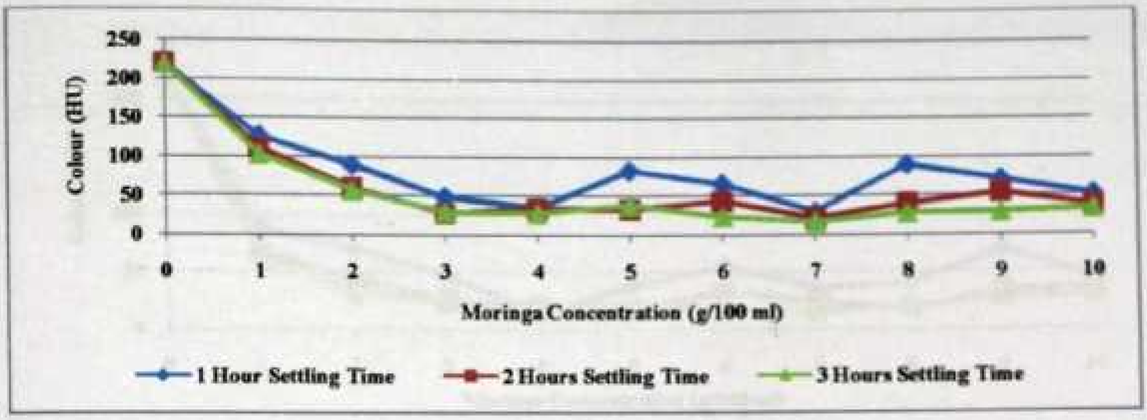

Fig. 4.1(c): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 6.5 ml.

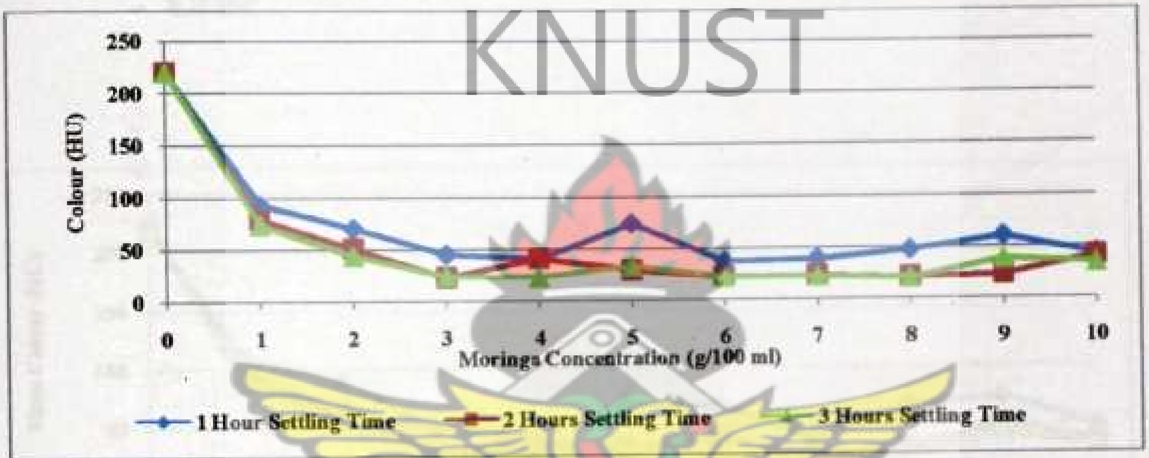

Fig. 4.1(d): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 7.0 ml.

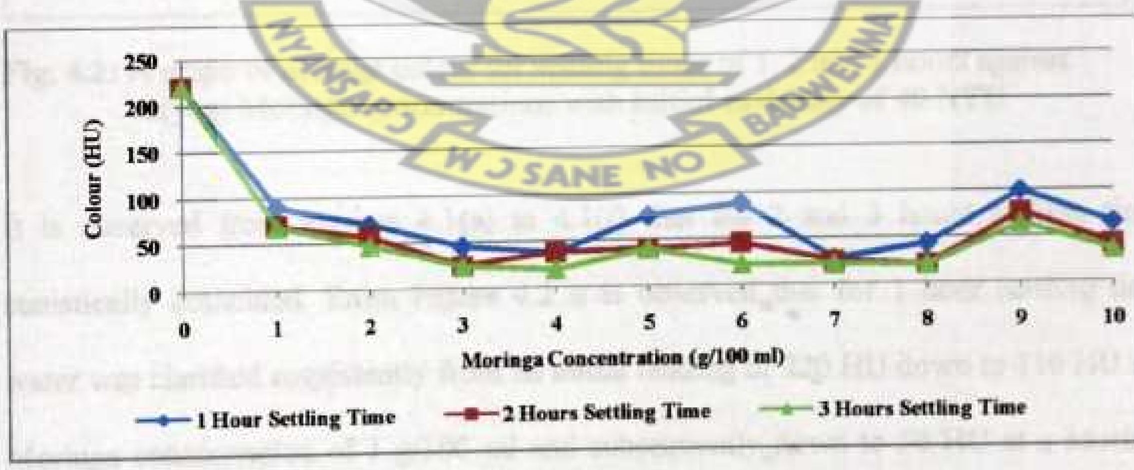

Fig. 4.1(e): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 7.5 ml.

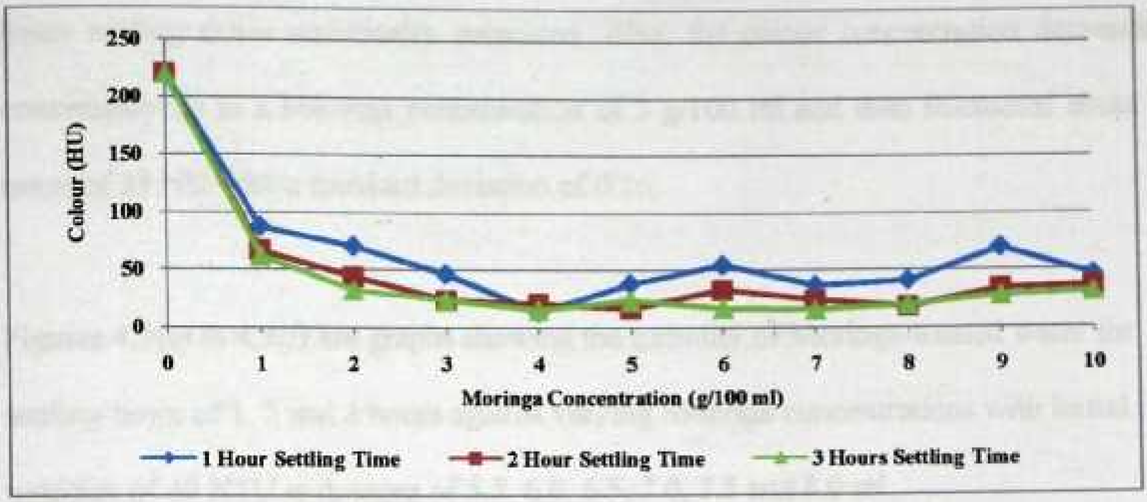

Fig. 4.1(f): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 8.0 ml.

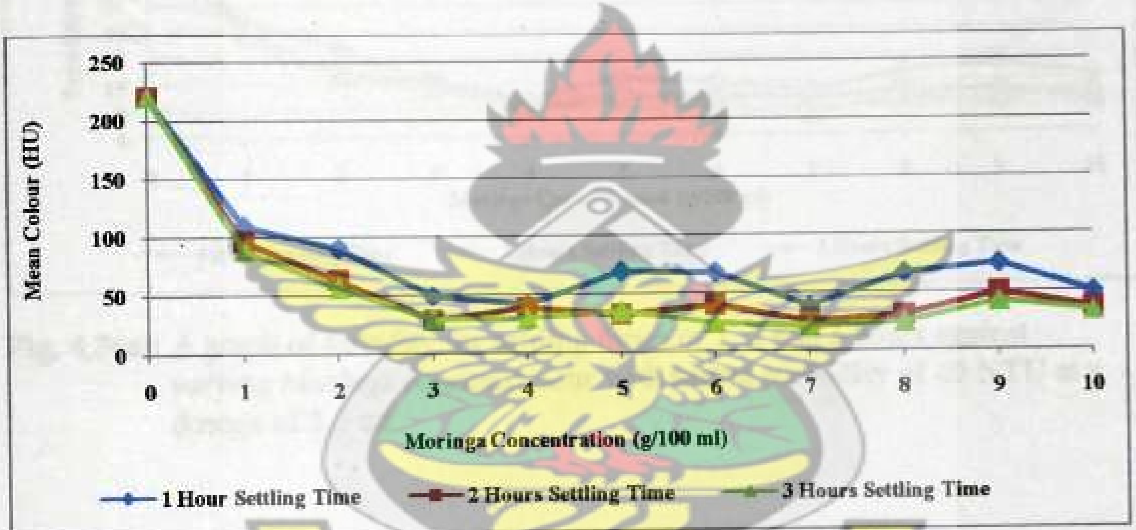

Fig. 4.2: A graph of average colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU**.

It is observed from Figures 4.1(a) to 4.1(f) that the 2 and 3 hours settling times statistically coincided. From Figure 4.2 it is observed that for 1 hour settling time, water was clarified consistently from an initial reading of 220 HU down to 110 HU at a Moringa concentration of 1 g/100 ml and subsequently down to 50 HU at a Moringa concentration of 3 g/100 ml. Thereafter, the mean units of colour fluctuated about a mean of 58 HU with a standard deviation of 14.84. Similarly, clarification at 2 and 3 hours settling times statistically coincided. Also, the colour concentration decreased consistently up to a Moringa concentration of 3 g/100 ml and then fluctuated about a mean of 33 HU with a standard deviation of 0.26.

Figures 4.3(a) to 4.3(f) are graphs showing the turbidity of Moringa-treated water for settling times of 1, 2 and 3 hours against varying Moringa concentrations with initial turbidity of 40 NTU at dosages of 5.5, 6.0, 6.5, 7.0, 7.5 and 8.0 ml.

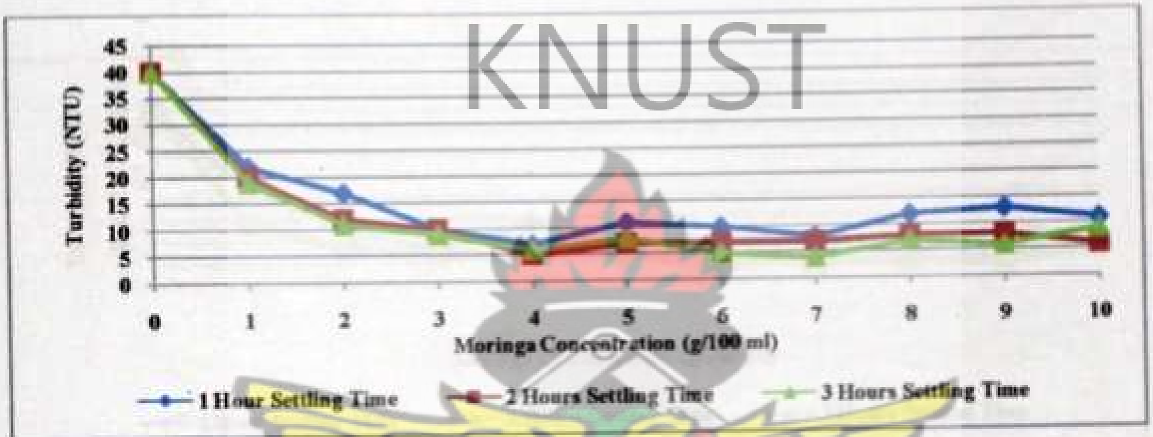

Fig. 4.3(a): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 5.5 ml.

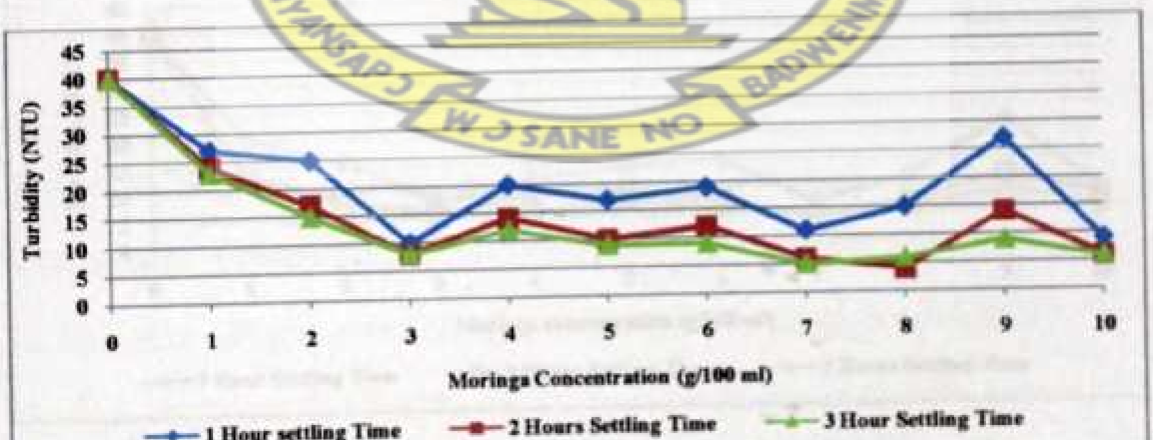

Fig. 4.3(b): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 6.0 ml.

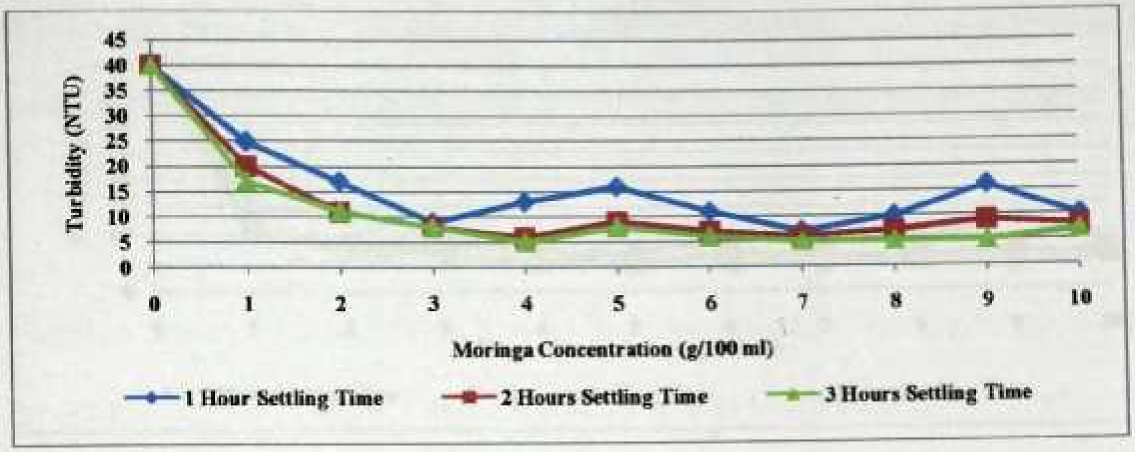

Fig. 4.3(c): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 6.5 ml.

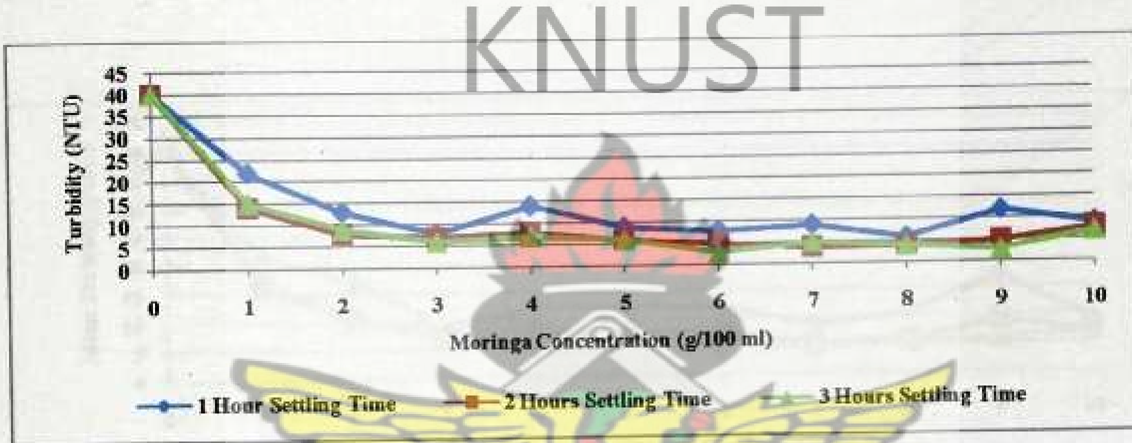

Fig. 4.3(d): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 7.0 ml.

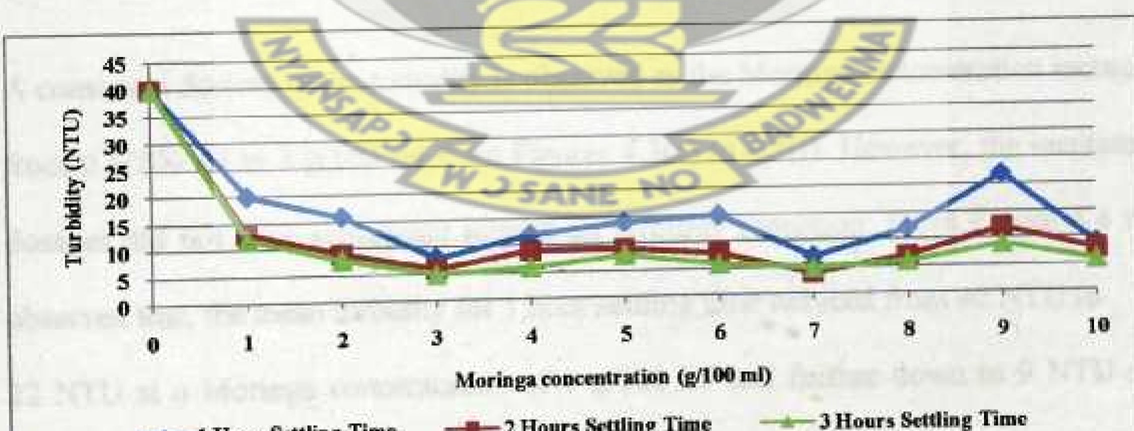

Fig. 4.3(e): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 7.5 ml.

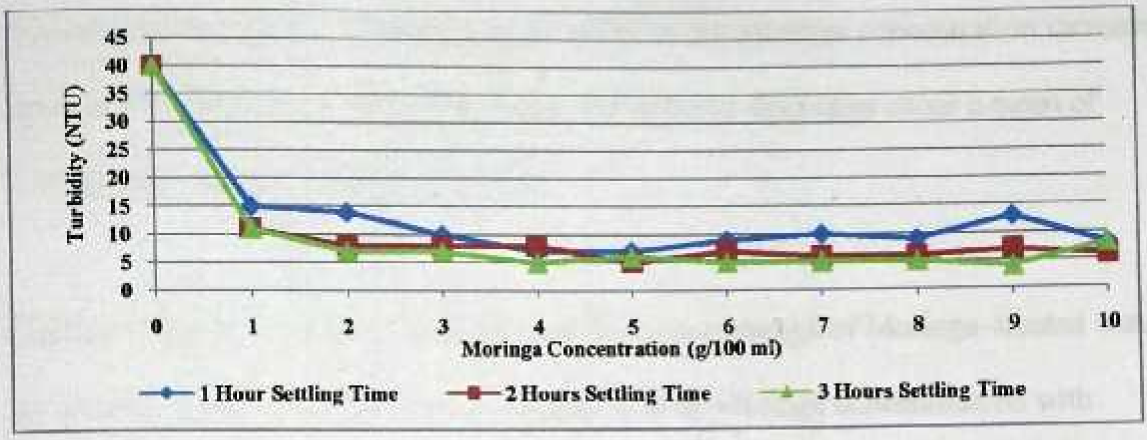

Fig. 4.3(f): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU** at a dosage of 8.0 ml.

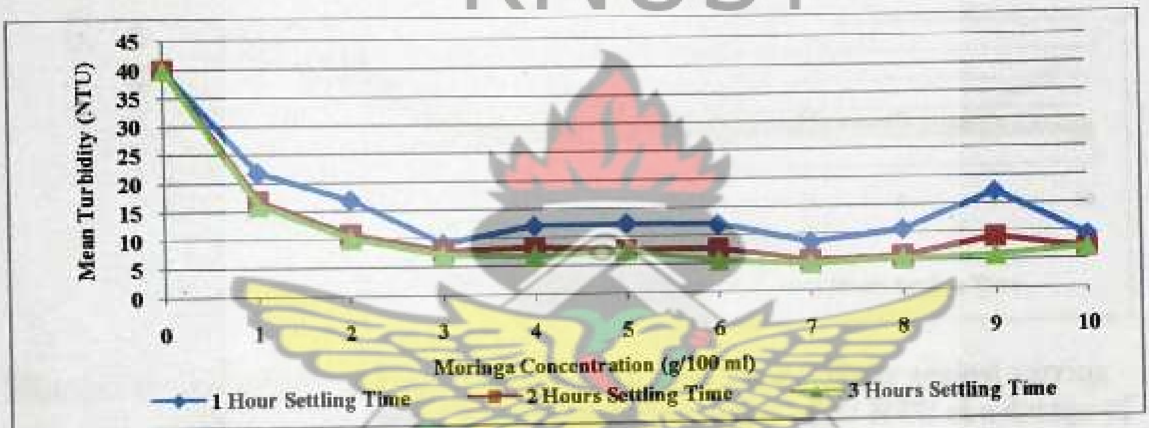

Fig. 4.4: A graph of average turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 40 NTU**.

A consistent decline in the turbidity is observed as the Moringa concentration increases from 0 g/100 ml to 3 g/100 ml from Figures 4.3(a) to 4.3(f). However, the increase in dosages did not have significant impact on turbidity reduction. From Figure 4.4 it is observed that, the mean turbidity for 1 hour settling time reduced from 40 NTU to 22 NTU at a Moringa concentration of 1 g/100 ml and further down to 9 NTU at a Moringa concentration of 3 g/100 ml. The turbidity thereafter, fluctuated about a mean of 12 NTU with a standard deviation of 2.78. The data for settling times of 2 and 3 hours statistically are similar as can be seen on Figure 4.4.

A consistent decline in the turbidity is observed as the Moringa concentration increases from 1 g/100 ml to 3 g/100 ml. Thereafter, the turbidity fluctuates about a mean of 7 NTU with a standard deviation of 0.22.

Figures 4.5(a) to 4.5(f) are graphs showing the colour change of Moringa–treated water for settling times of 1, 2 and 3 hours against varying Moringa concentrations with initial turbidity of 27 NTU (Wet season) at dosages of 5.5, 6.0, 6.5, 7.0, 7.5 and 8.0 ml.

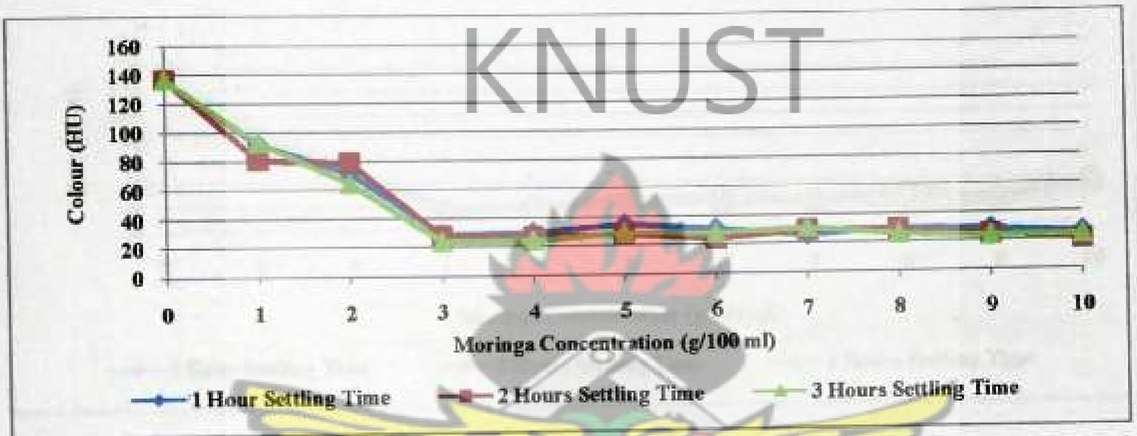

Fig. 4.5(a): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 5.5 ml.

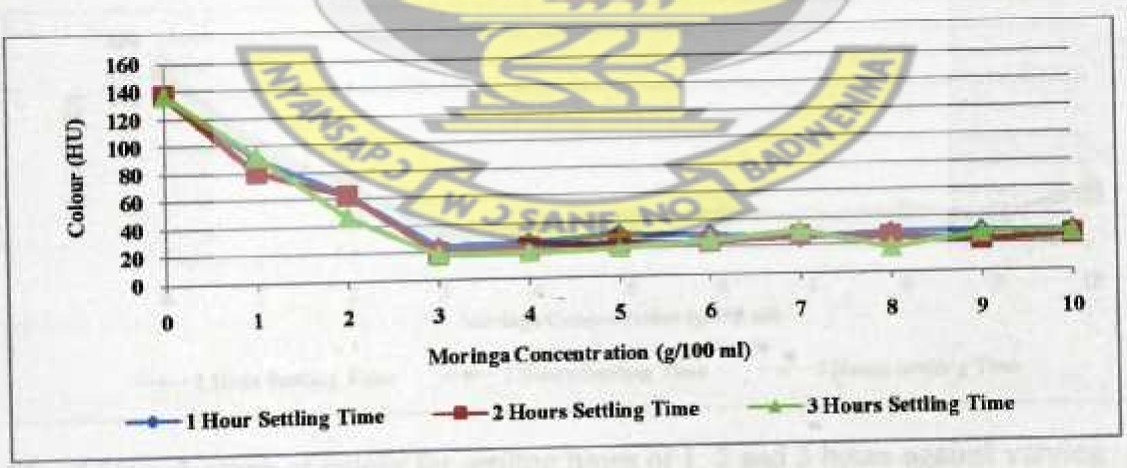

Fig. 4.5(b): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 6.0 ml.

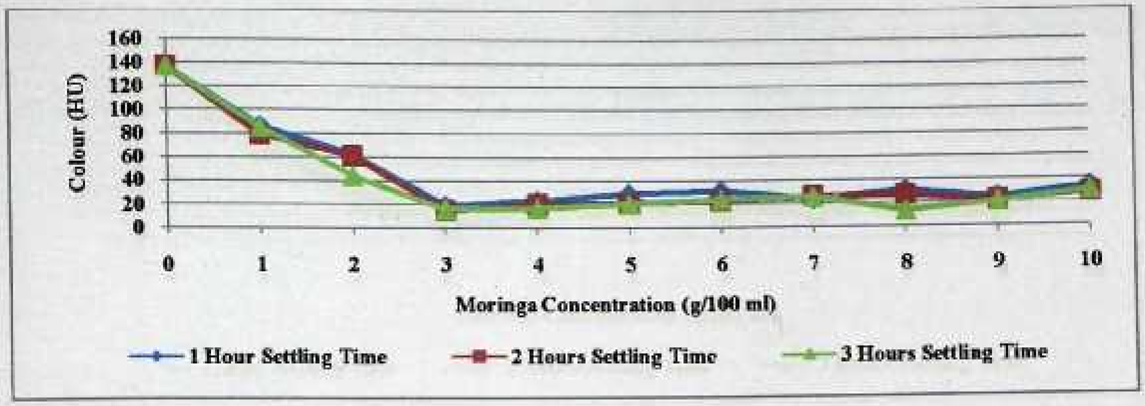

Fig. 4.5(c): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 6.5 ml.

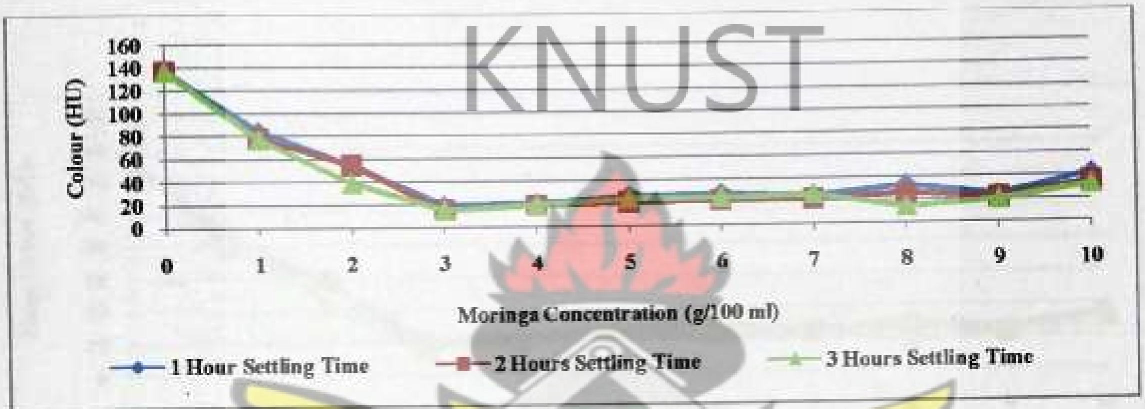

Fig. 4.5(d): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 7.0 ml.

Fig. 4.5(e): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 7.5 ml.

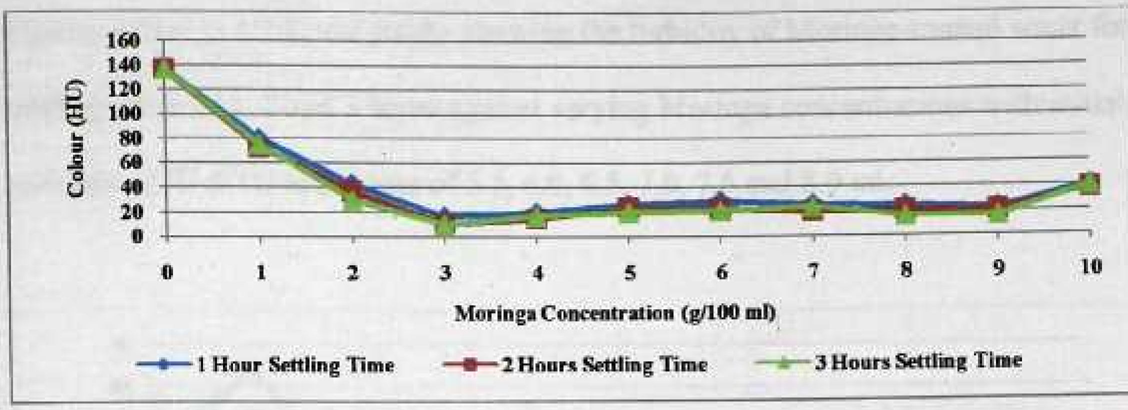

Fig. 4.5(f): A graph of colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 8.0 ml.

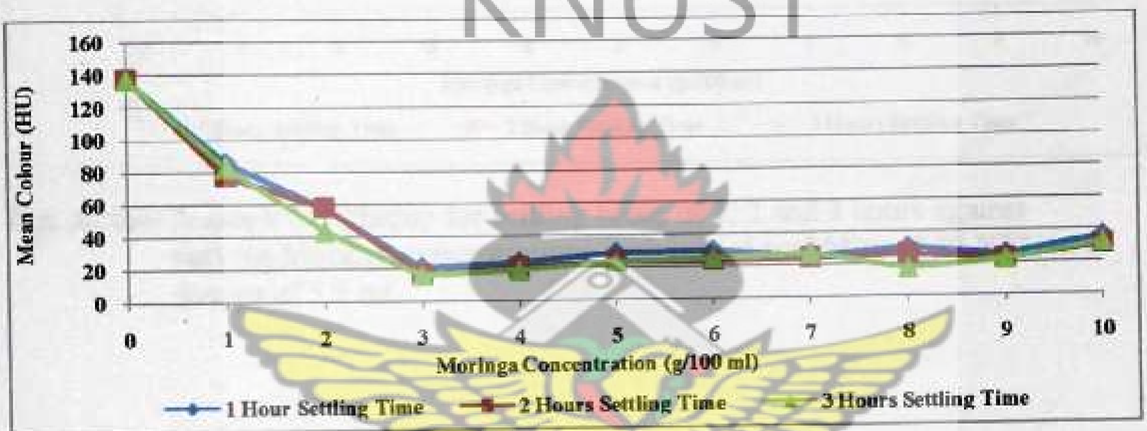

Fig. 4.6: A graph of average colour for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU**.

It is observed from Figures 4.5(a) to 4.5(f) that, the settling time is insignificant when the initial turbidity is 27 NTU. A consistent decline in colour is observed from a Moringa concentration of 0 g/100 ml to 3 g/100 ml, thereafter the colour fluctuated about a mean value. From Figure 4.6 it is observed that, the mean units of colour decreases consistently from a Moringa concentration of 0 g/100 ml to 3 g/100 ml for all the settling times. Beyond the concentration of 3 g/100 ml the units of colour fluctuated about a mean of 25 HU with a standard deviation of 0.86.

Figures 4.7(a) to 4.7(f) are graphs showing the turbidity of Moringa-treated water for settling times of 1, 2 and 3 hours against varying Moringa concentrations with initial turbidity of 27 NTU at dosages of 5.5, 6.0, 6.5, 7.0, 7.5 and 8.0 ml.

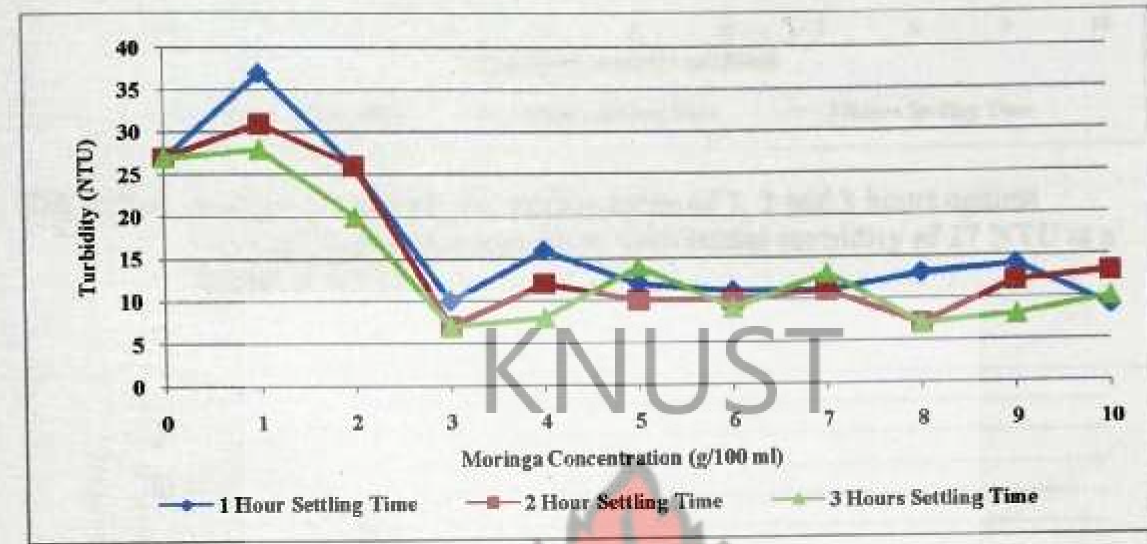

Fig. 4.7(a): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 5.5 ml.

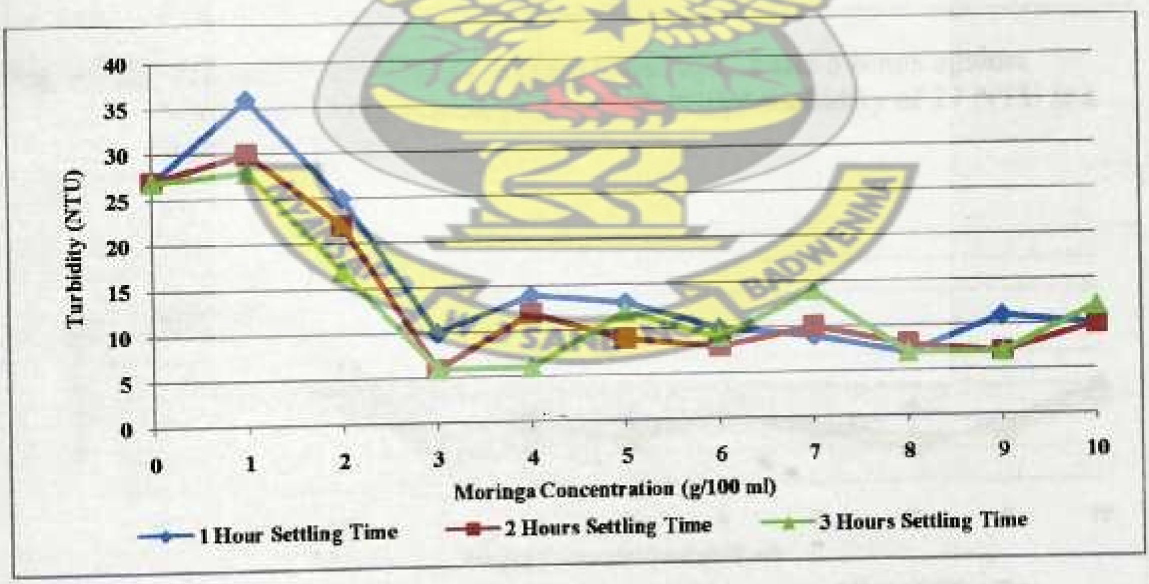

Fig. 4.7(b): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 6.0 ml.

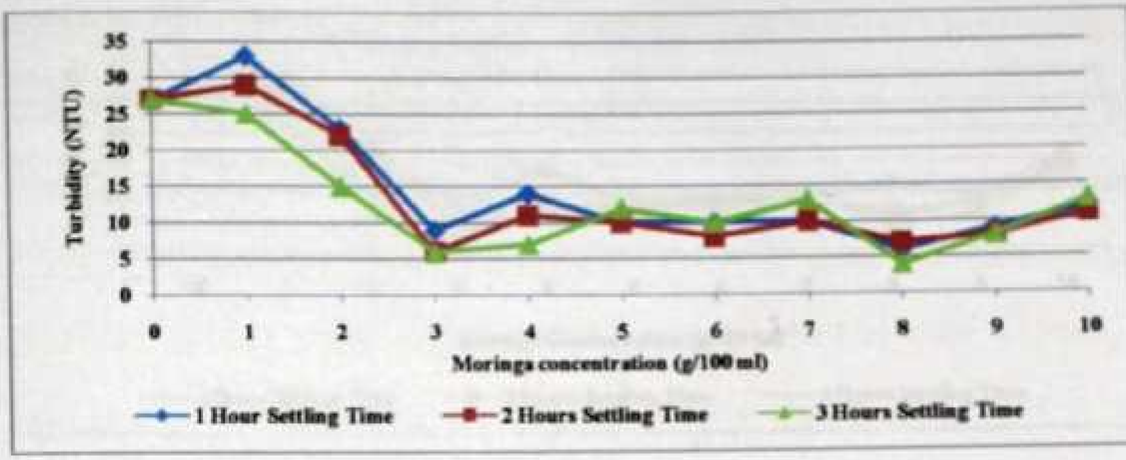

Fig. 4.7(c): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 6.5 ml.

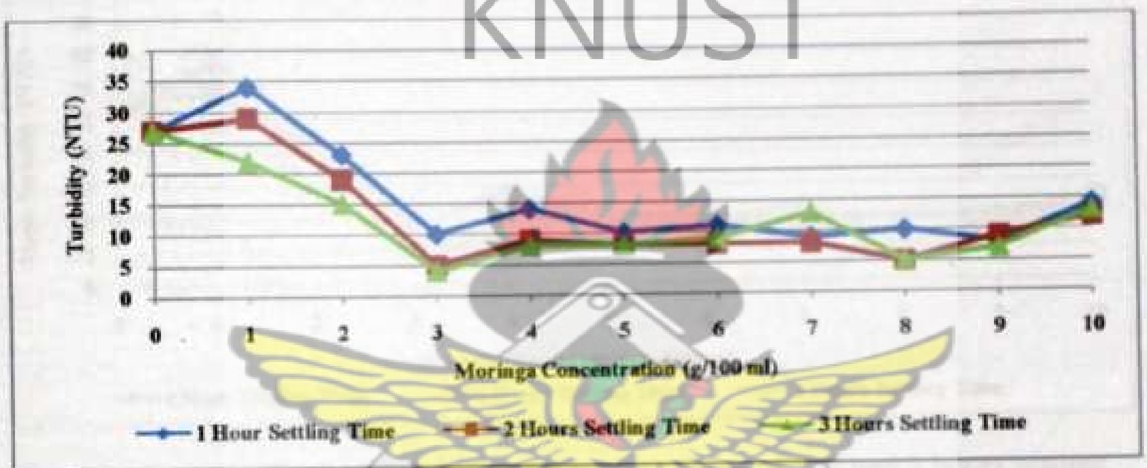

Fig. 4.7(d): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 7.0 ml.

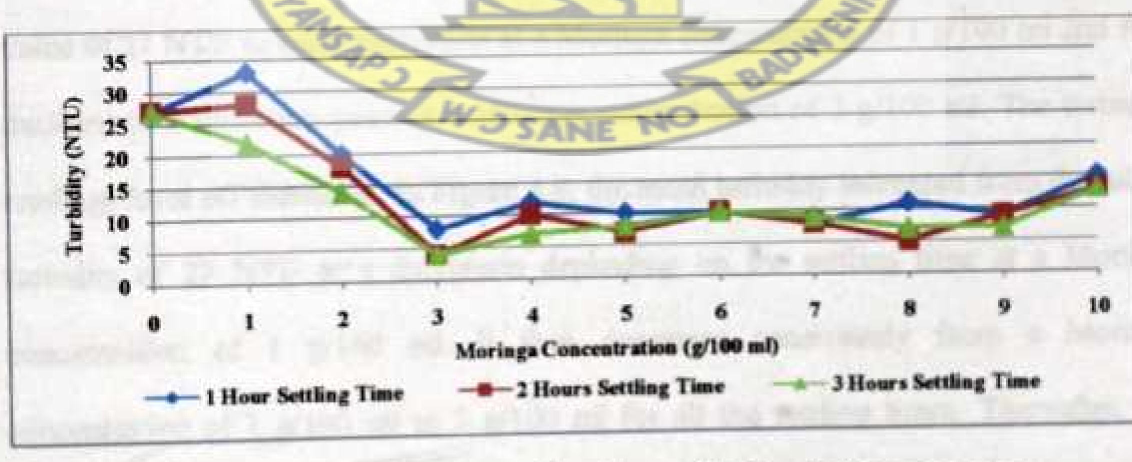

Fig. 4.7(e): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 7.5 ml.

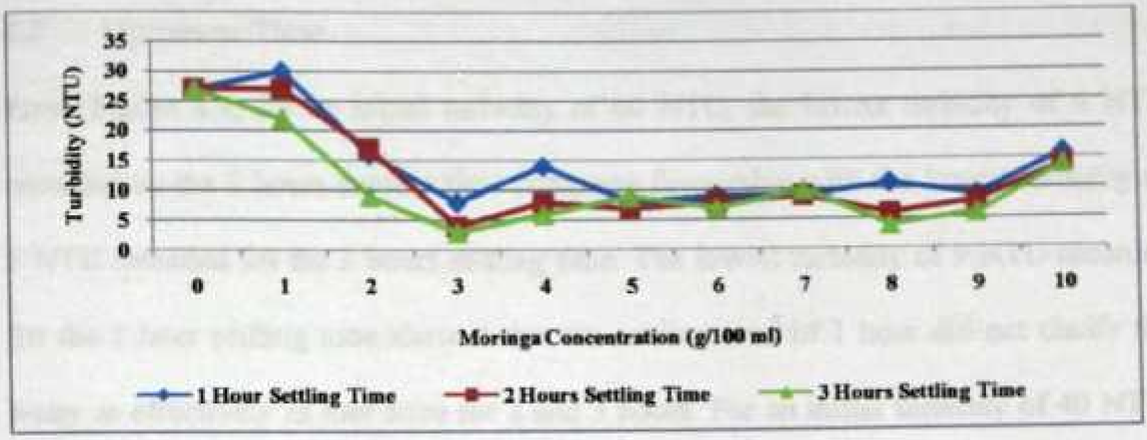

Fig. 4.7(f): A graph of turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU** at a dosage of 8.0 ml.

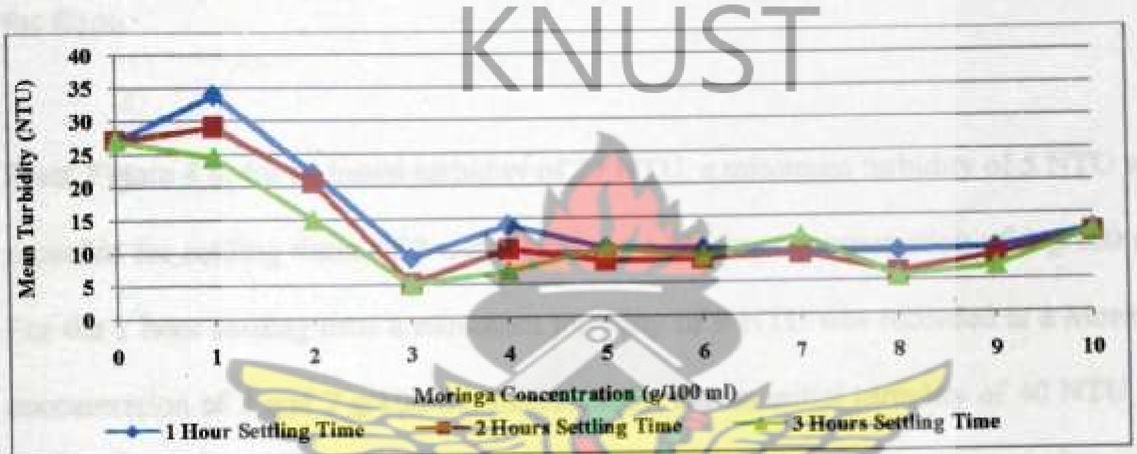

Fig. 4.8: A graph of average turbidity for settling times of 1, 2 and 3 hours against varying Moringa concentrations with **initial turbidity of 27 NTU**.

It is observed from Figures 4.7(a) to 4.7(f) that, the turbidity increased from the initial value of 27 NTU to some maximum at a Moringa concentration of 1 g/100 ml and then declined to a minimum point at a Moringa concentration of 3 g/100 ml. The turbidity readings level off thereafter. In Figure 4.8, the mean turbidity increased from the initial turbidity of 27 NTU to a maximum depending on the settling time at a Moringa concentration of 1 g/100 ml. It then decreases consistently from a Moringa concentration of 1 g/100 ml to 3 g/100 ml for all the settling times. Thereafter, the turbidity fluctuates about a mean of 10 NTU with a standard deviation of 0.51.

4.2 Optimum Time

From Figure 4.4, for an initial turbidity of 40 NTU, the lowest turbidity of 6 NTU recorded on the 2 hours settling time compares favourably with the lowest turbidity of 5 NTU recorded for the 3 hours settling time. The lowest turbidity of 9 NTU recorded for the 1 hour settling time showed that the settling time of 1 hour did not clarify the water as effectively as that done for 2 and 3 hours. For an initial turbidity of 40 NTU, colour variation on Figure 4.2 followed a similar trend as on Figure 4.4 indicating that clarification at 1 hour of settling time was not as effective as 2 and 3 hours in settling the flocs.

From Figure 4.8, for an initial turbidity of 27 NTU, a minimum turbidity of 5 NTU was recorded for settling times of 2 and 3 hours at a Moringa concentration of 3 g/100 ml. For the 1 hour settling time a minimum turbidity of 9 NTU was recorded at a Moringa concentration of 3 and 7 g/100 ml. Interestingly, for an initial turbidity of 40 NTU the minimum turbidity recorded for settling times of 2 and 3 hours is also 5 NTU at a Moringa concentration of 7 g/100 ml (Figure 4.4).

From Figure 4.6, a minimum colour of 17 HU was recorded at a Moringa concentration of 3 g/100 ml for a settling time of 2 hours. This was similar to a minimum colour of 16 HU for a settling time of 3 hours. A minimum colour of 21 HU was recorded for the 1 hour settling time which exceeds the minimum colour values of 17 HU and 16 HU recorded at 2 and 3 hours settling times respectively.

Although the minimum turbidity and minimum colour were recorded at the 3 hours settling time, it will be better to select 2 hours settling time as the optimum time. This is because the results did not reveal any significant difference between the two times. From the foregoing analysis the optimum time for treatment is 2 hours of settling time. In water treatment, the settling time determines how fast the water is moved on from the settling stage. Thus longer settling time could affect the production rate. However, for a raw water sample with low initial turbidity of 27 NTU the settling time did not have a significant impact on the treatment performance.

4.3 DETERMINATION OF OPTIMUM TREATMENT PERFORMANCE OF DIFFERENT CONCENTRATION OF *MORINGA OLEIFERA* UPON APPLICATION TO WATER

Figures 4.9 to 4.14 are graphical representations of the performance of *Moringa oleifera* application to raw water with initial turbidities of 40 NTU and 27 NTU respectively.

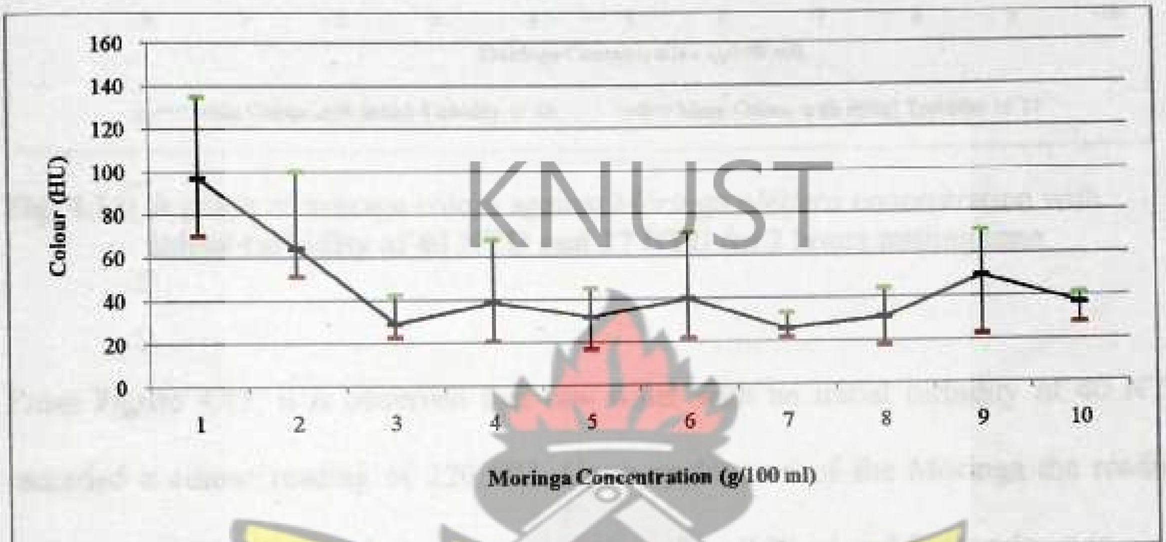

Fig. 4.9: A graph of colour against *Moringa oleifera* concentration with **initial turbidity of 40 NTU** for 2 hours settling time.

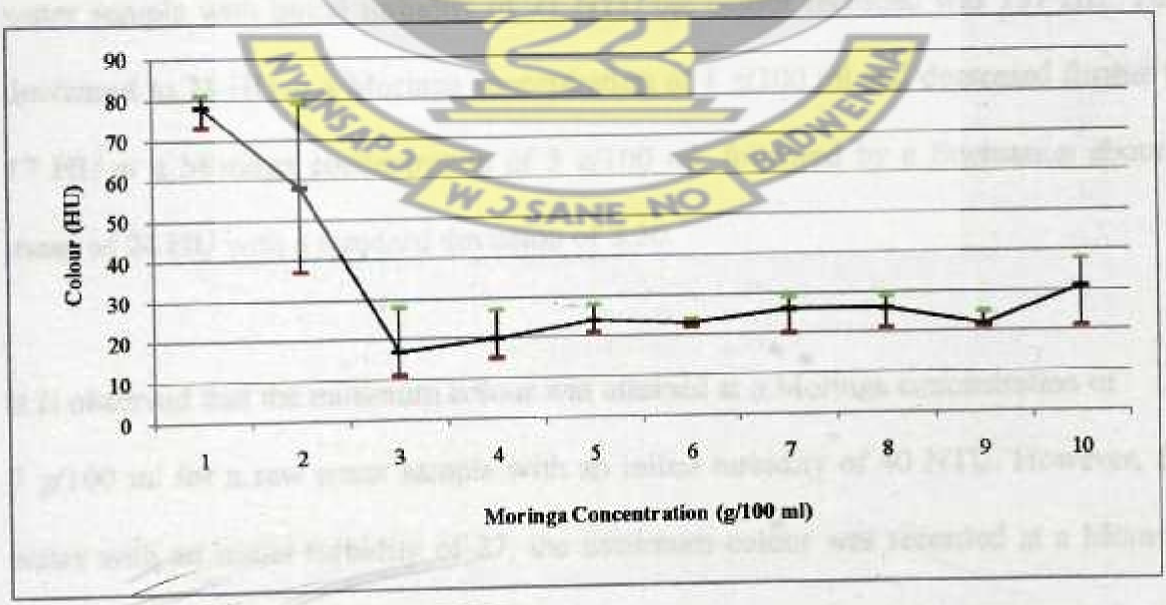

Fig. 4.10: A graph of colour against *Moringa oleifera* concentration with **initial turbidity of 27 NTU** for 2 hours settling time.

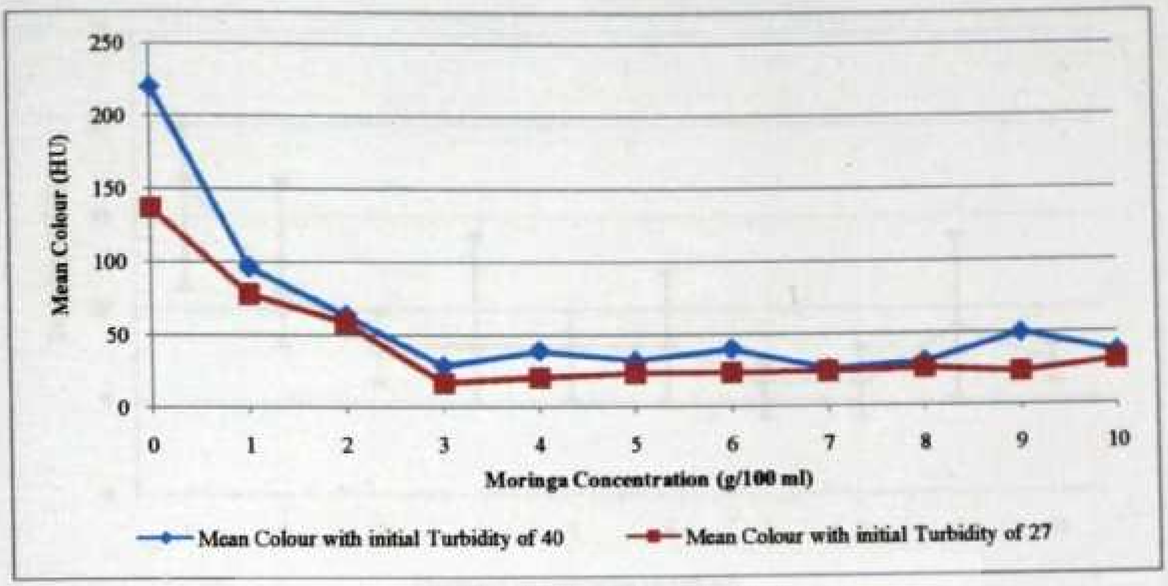

Fig. 4.11: A graph of average colour against *Moringa oleifera* concentration with initial turbidity of 40 NTU and 27 NTU for 2 hours settling time.

From Figure 4.11, it is observed that raw water with an initial turbidity of 40 NTU recorded a colour reading of 220 HU. Upon application of the Moringa the reading decreased to 97 HU at a Moringa concentration of 1 g/100 ml and further down to 29 HU at a Moringa concentration of 3 g/100 ml. Thereafter, the colour reading fluctuated about a mean reading of 36 HU with a standard deviation of 7.73. For raw water sample with initial turbidity of 27 NTU the colour recorded was 137 HU. This decreased to 78 HU at a Moringa concentration of 1 g/100 ml and decreased further to 17 HU at a Moringa concentration of 3 g/100 ml, followed by a fluctuation about a mean of 24 HU with a standard deviation of 3.30.

It is observed that the minimum colour was attained at a Moringa concentration of 7 g/100 ml for a raw water sample with an initial turbidity of 40 NTU. However, for water with an initial turbidity of 27, the minimum colour was recorded at a Moringa concentration of 3 g/100 ml.

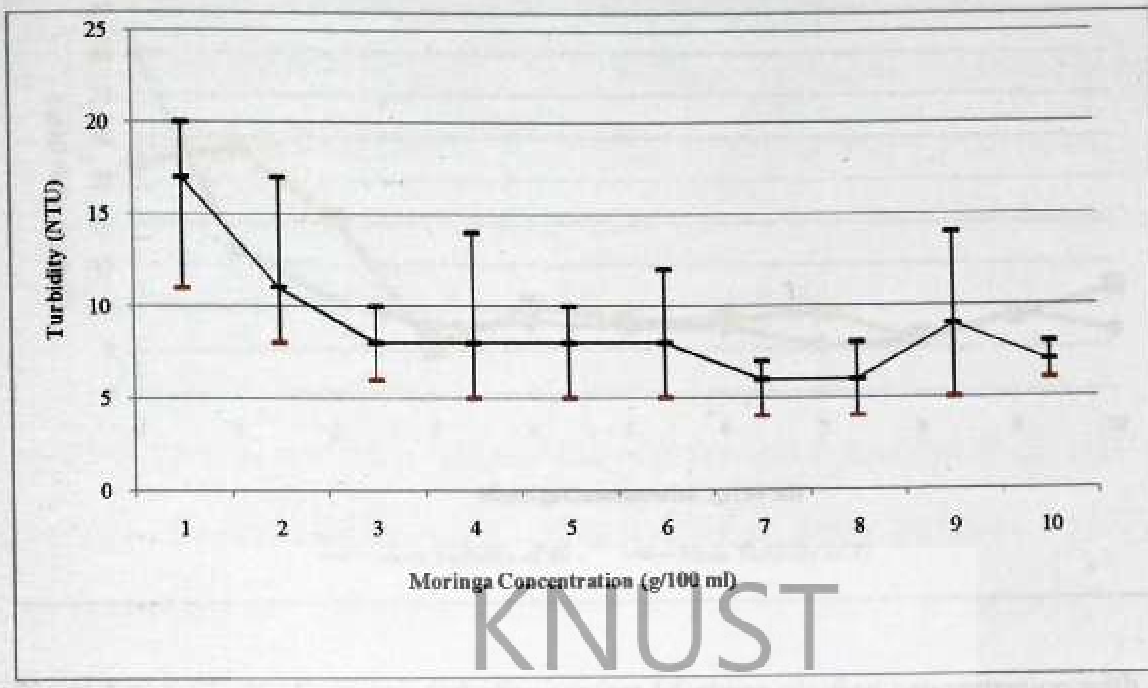

Fig. 4.12: A graph of turbidity against *Moringa oleifera* concentration with **initial turbidity of 40 NTU** for 2 hours settling time.

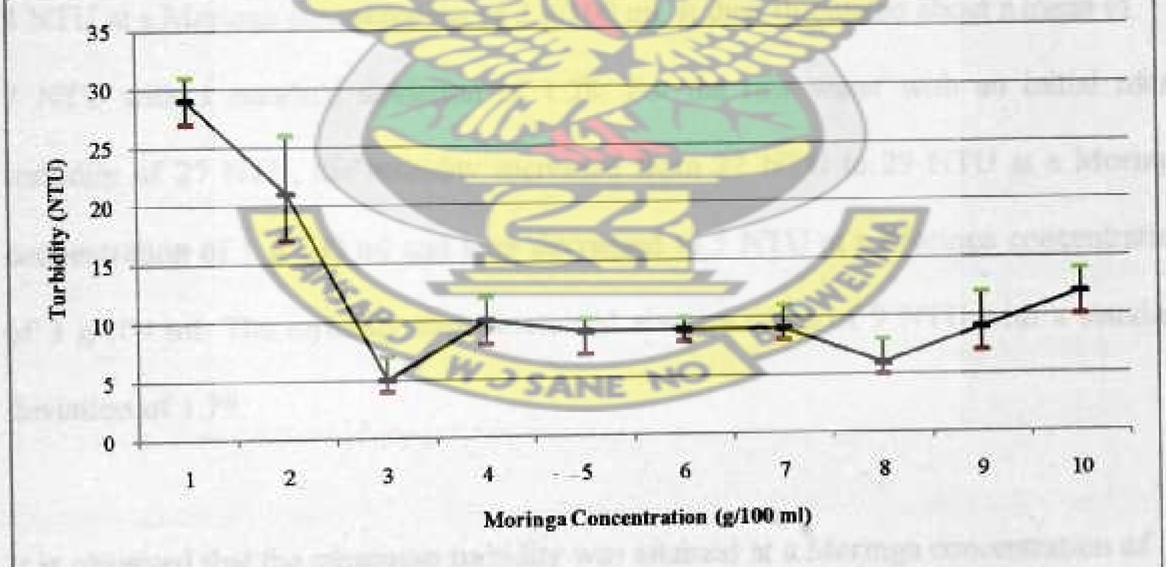

Fig. 4.13: A graph of turbidity against *Moringa oleifera* concentration with **initial turbidity of 27 NTU** for 2 hours settling time.

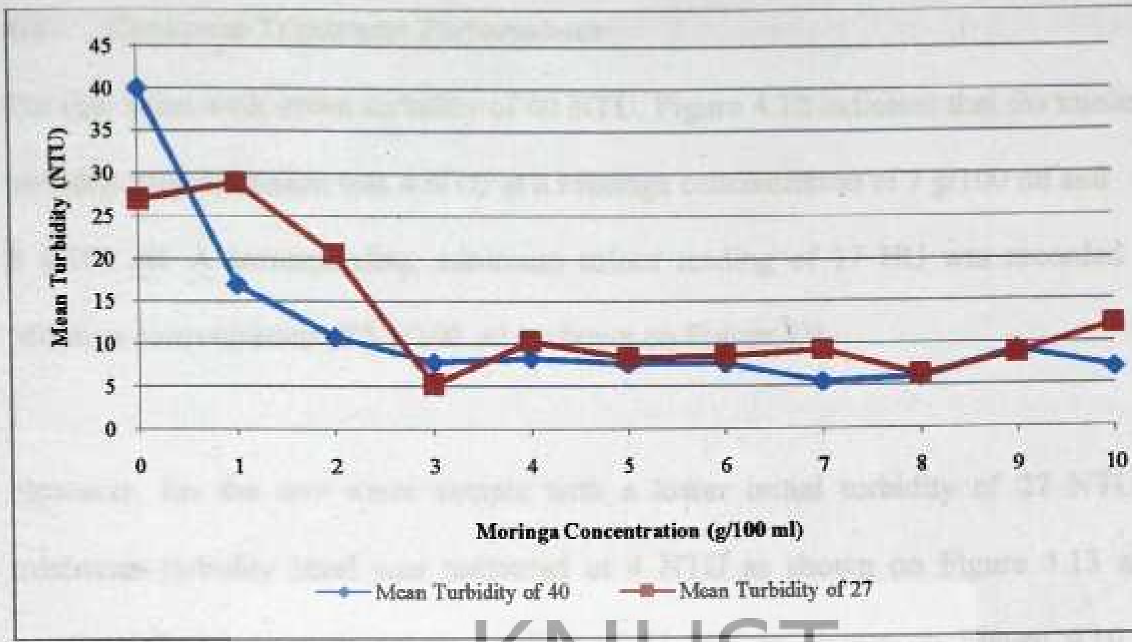

Fig. 4.14: A graph of average turbidity against *Moringa oleifera* concentration with initial turbidity of 40 NTU and 27 NTU for 2 hours settling time.

From Figures 4.14, it is observed that the initial mean turbidity of 40 NTU decreased from 40 NTU to 17 NTU at a Moringa concentration of 1 g/100 ml and further down to 8 NTU at a Moringa concentration of 3 g/100 ml. It then fluctuated about a mean of 7 NTU with a standard deviation of 1.28. For the raw water with an initial mean turbidity of 27 NTU, the turbidity increased from 27 NTU to 29 NTU at a Moringa concentration of 1 g/100 ml and later decreased to 5 NTU at a Moringa concentration of 3 g/100 ml. The turbidity then fluctuated about a mean of 9 NTU with a standard deviation of 1.79.

It is observed that the minimum turbidity was attained at a Moringa concentration of 7 g/100 ml for a raw water sample with an initial turbidity of 40 NTU. However, for water with an initial turbidity of 27 NTU, the minimum turbidity was recorded at a Moringa concentration of 3 g/100 ml.

4.4 Optimum Treatment Performance

For raw water with initial turbidity of 40 NTU, Figure 4.12 indicates that the minimum turbidity after treatment was 4 NTU at a Moringa concentration of 7 g/100 ml and 8 g/100 ml. A corresponding minimum colour reading of 17 HU was recorded at a Moringa concentration of 5 g/100 ml is shown on Figure 4.9.

However, for the raw water sample with a lower initial turbidity of 27 NTU the minimum turbidity level was measured at 4 NTU as shown on Figure 4.13 and a corresponding minimum colour reading of 11 HU as shown on Figure 4.10 at a Moringa concentration of 3 g/100 ml.

Again, for raw water with initial turbidity of 40 NTU, Figure 4.14 indicates that the lowest turbidity after treatment was 6 NTU at a Moringa concentration of 7 g/100 ml. A corresponding low colour reading at 26 HU at the same Moringa concentration is shown on Figure 4.11.

However, for the raw water sample with a lower initial turbidity of 27 NTU the lowest turbidity level was measured at 5 NTU as shown on Figure 4.14 and a corresponding low colour reading of 17 HU as shown on Figure 4.11 at a Moringa concentration of 3 g/100 ml. It is observed that for the raw water sample with initial turbidity of 40 NTU the measurements made at Moringa concentration of 3 g/100 ml statistically fall within the measurements of those done at a Moringa concentration of 7 g/100 ml.

Secondly, from Figures 4.11 and 4.14, the water treatment performance at the Moringa concentration of 3 g/100 ml was consistent for the raw water turbidity of 40 NTU and 27 NTU as compared to the Moringa concentration of 7 g/100 ml.

It is therefore prudent to use a lower concentration of 3 g/100 ml and still obtain results within the range of that applied with a Moringa concentration of 7 g/100 ml. From the foregoing, it can be deduced that the optimum Moringa concentration for treatment is 3 g/100 ml.

4.5 COMPARISON OF *MORINGA OLEIFERA* AND ALUM WITH RESPECT TO pH AND ALKALINITY

Having established the optimum time of 2 hours and concentration of 3 g/100 ml for the treatment, subsequent analysis was conducted comparing the performances of alum-treated water to Moringa-treated water.

Figures 4.15 to 4.18 show the performance of *Moringa oleifera* and alum with respect to pH changes of the two treatments with varying levels of initial turbidity.

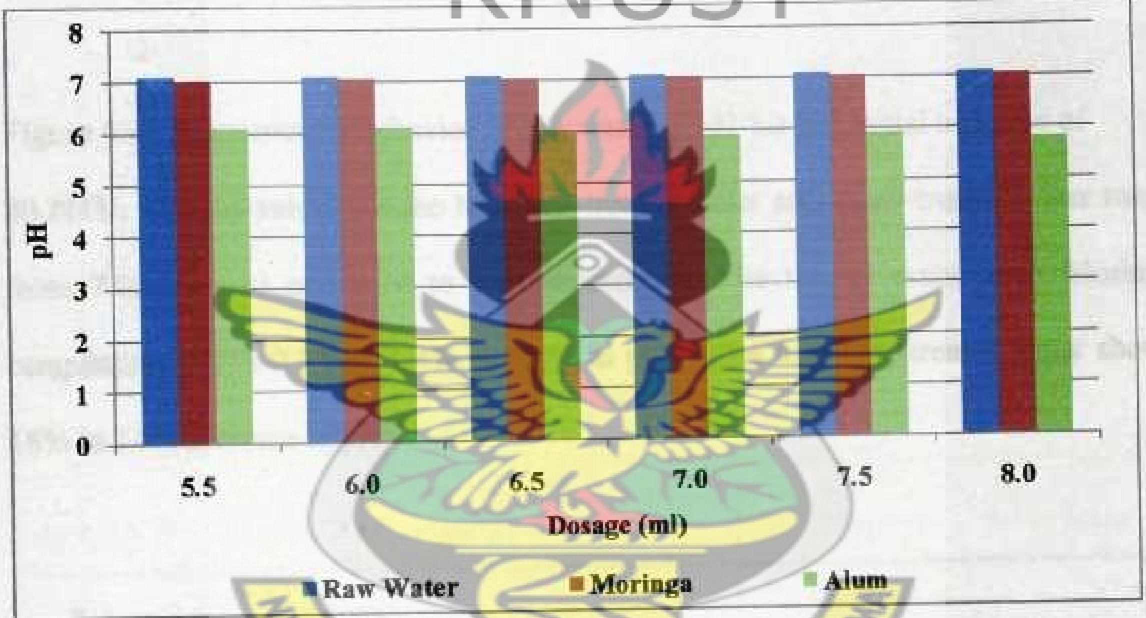

Fig. 4.15: pH changes of Moringa–treated water and alum–treated water with **initial turbidity of 105 NTU** and pH of 7.10 at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.15 indicates that Moringa–treated water showed a decrease in pH from 7.10 to between 7.02 and 7.05. This represents a 1.1% to 0.7% decline. Upon treatment with alum, however, the pH level decreased to between 5.80 and 6.10, representing a 18% to 14% decrease.

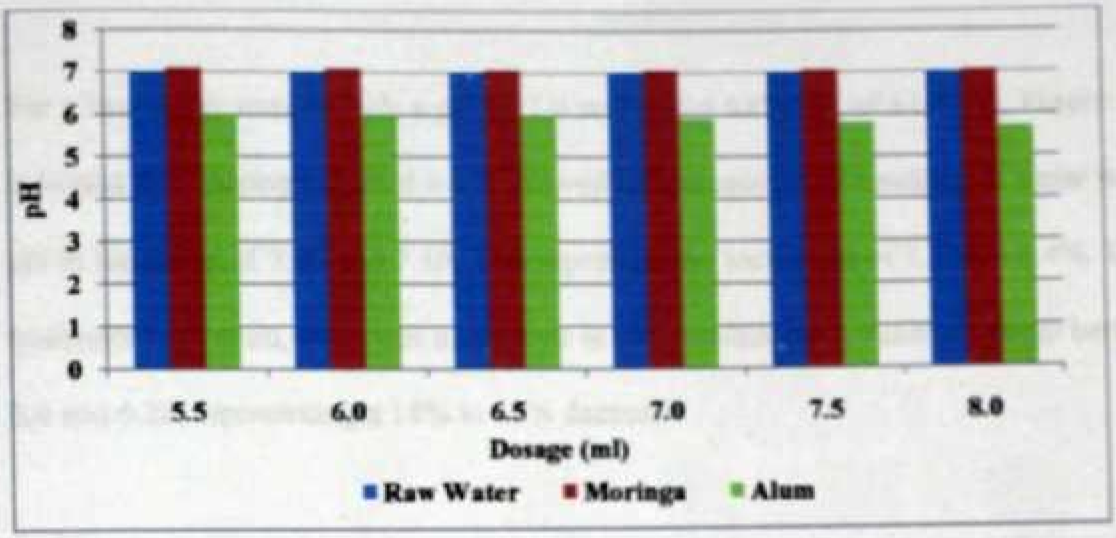

Fig. 4.16: pH changes of Moringa–treated water and alum–treated water with **initial turbidity of 80 NTU** and pH of 7.0 at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.16 represents the behavior of raw water of pH 7.0 and initial turbidity of 80 NTU. The pH values for the Moringa–treated water and alum–treated water range from 7.05 to 7.10 and 5.70 to 6.0 respectively. The treated water after Moringa coagulation shows 0.7% to 1.4% increase in pH whiles the alum–treated water shows 18% to 14% decrease in pH.

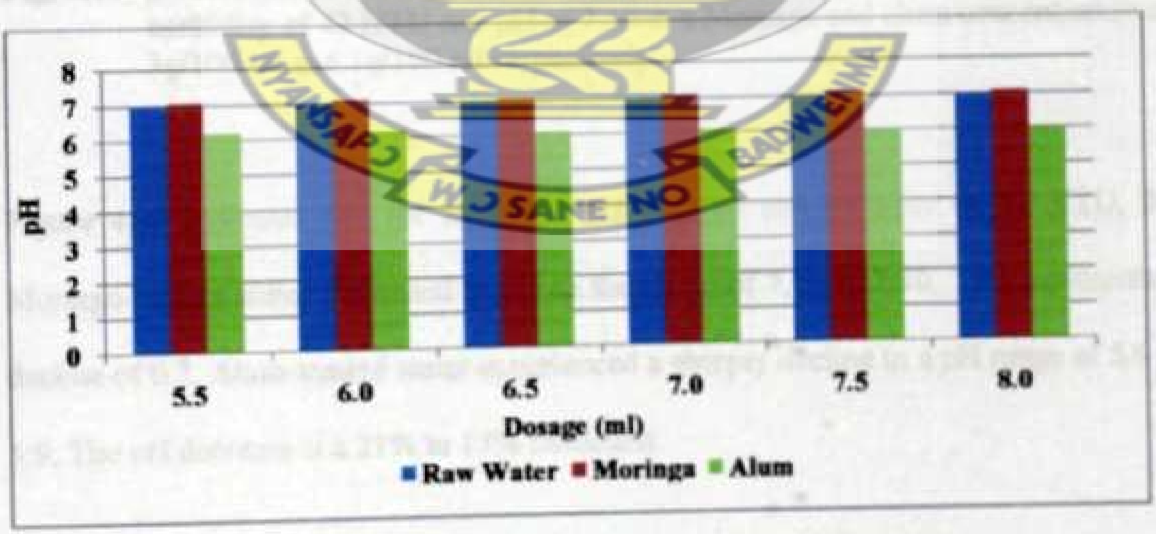

Fig. 4.17: pH changes of Moringa–treated water and alum–treated water with **initial turbidity of 61 NTU** and pH of 7.0 at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with a pH of 7.0 and initial turbidity of 61 NTU, Figure 4.17 indicates that Moringa–treated water showed an increase in pH resulting in water with a pH in the range of 7.08 and 7.10. This represents an increment of 1.1% to 1.4%. Upon treatment with alum, there was a decrease in pH, resulting in a water pH range between 6.0 and 6.20, representing a 14% to 11% decrease.

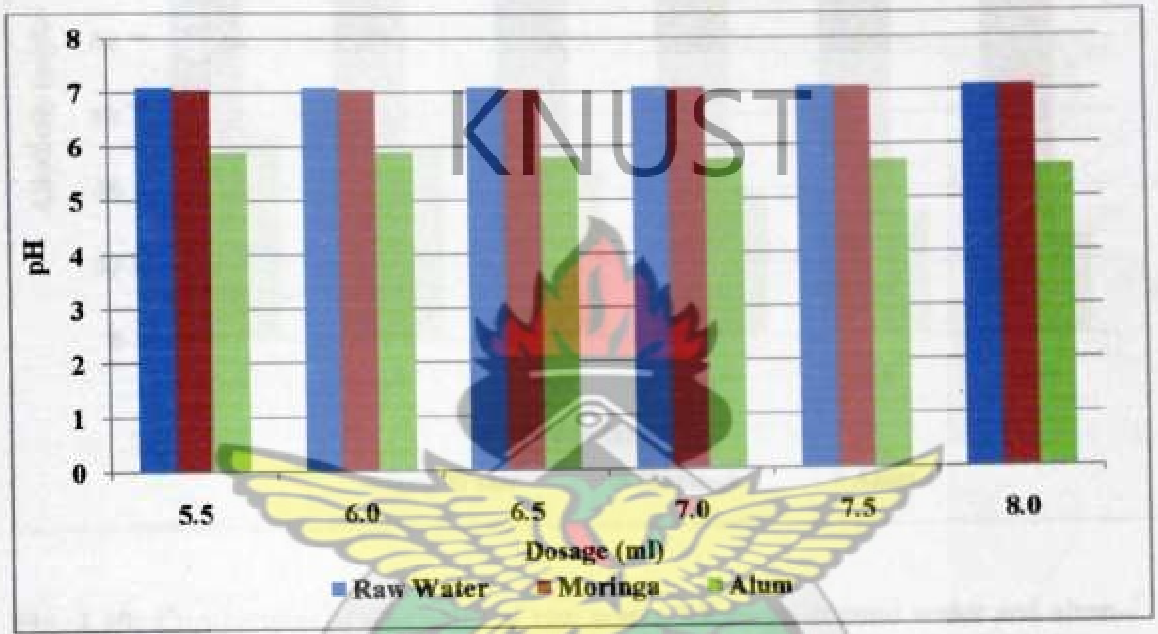

Fig. 4.18: pH changes of Moringa–treated water and alum–treated water with **initial turbidity of 42 NTU** and pH of 7.10 at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.18 indicates that for an initial pH of 7.10 and turbidity of 42 NTU, the Moringa-treated water decreased in pH to the range of 7.05 to 7.10. This represents a decline of 0.7. Alum-treated water experienced a sharper decline to a pH range of 5.6 to 5.9. The pH decrease is a 21% to 17% reduction.

Figures 4.19 to 4.22 are graphical representation of the performance of *Moringa oleifera* and alum in terms of alkalinity with initial turbidities of 105 NTU, 80 NTU, 61 NTU and 42 NTU.

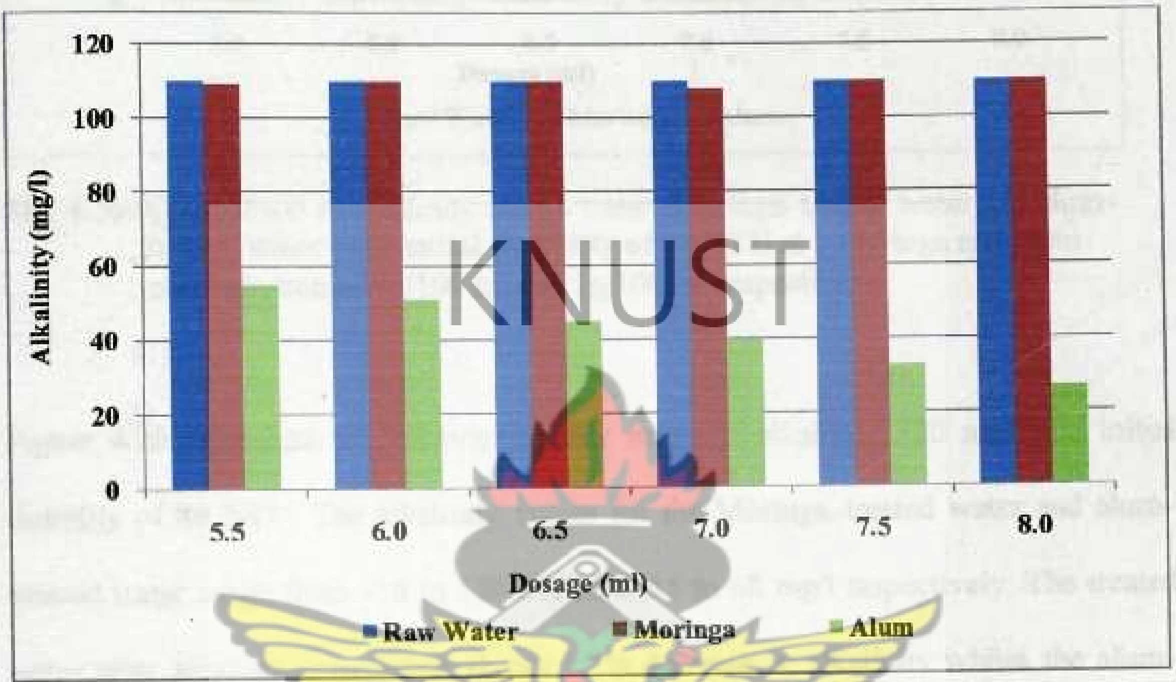

Fig. 4.19: Comparison of alkalinity of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 105 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with an alkalinity of 110 mg/l and initial turbidity of 105 NTU, Figure 4.19 indicates that Moringa–treated water showed a decrease in alkalinity to 108 mg/l. This represents a 1.8% decline. Upon treatment with alum, however, the alkalinity decreased to between 55 mg/l and 27 mg/l, representing a 75% to 50% decline.

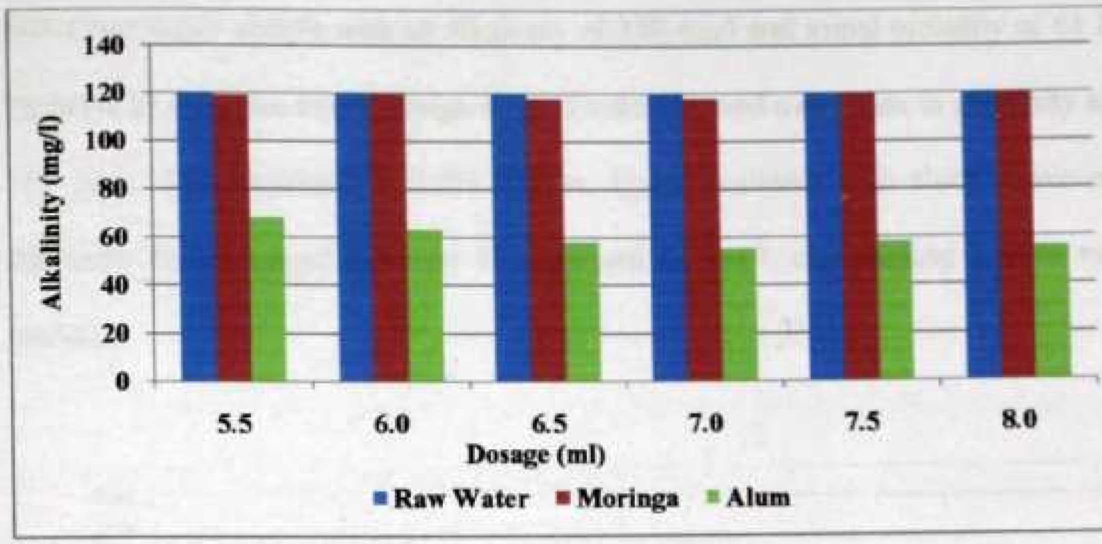

Fig. 4.20: Comparison of alkalinity of raw water, Moringa–treated water and alum–treated water **with initial turbidity of 80 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.20 represents the behavior of raw water of alkalinity 120 mg/l and initial turbidity of 80 NTU. The alkalinity values for the Moringa–treated water and alum–treated water range from 118 to 120 mg/l and 55 to 68 mg/l respectively. The treated water after Moringa coagulation shows 1.7% decrease in alkalinity whiles the alum–treated water shows 54% to 43% decrease in alkalinity.

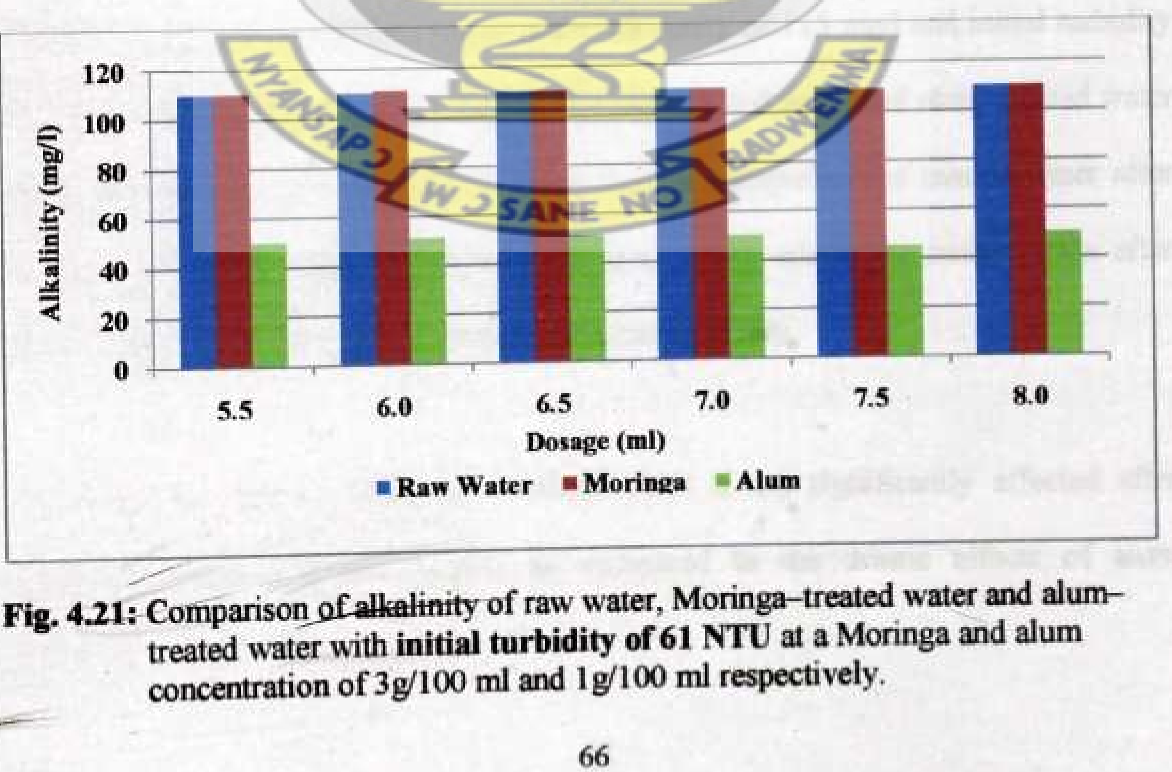

Fig. 4.21: Comparison of alkalinity of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 61 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with an alkalinity of 110 mg/l and initial turbidity of 61 NTU, Figure 4.21 indicates that Moringa–treated water showed a decrease in alkalinity to 109 mg/l. This represents a 0.9% decline. Upon treatment with alum, however, the alkalinity levels ranged between 45 mg/l and 50 mg/l, representing a 59% to 55% decline.

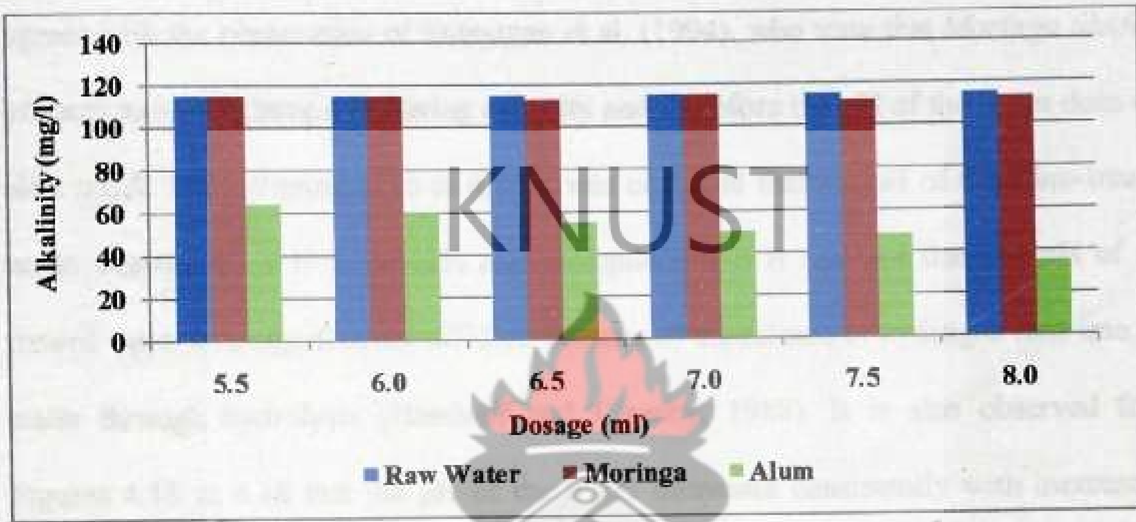

Fig. 4.22: Comparison of alkalinity of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 42 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.22 represents changes in raw water alkalinity of 115 mg/l and initial turbidity of 42 NTU. The alkalinity values for the Moringa–treated water and alum–treated water range from 112 to 115 mg/l and 35 to 64 mg/l respectively. The treated water after Moringa coagulation shows 2.6% decrease in alkalinity whiles the treated water after alum coagulation shows 70% to 44% decrease in alkalinity.

It is observed that the alkalinity of final water is not significantly affected after coagulation with *Moringa oleifera* as compared to the drastic effects of alum application.

4.6 pH and Alkalinity

Figures 4.15 and 4.18 show that, for a raw water sample with initial pH of 7.10 there was a 1.1% to 0.7% decrease in pH of the treated water after *Moringa oleifera* coagulation. However, from Figures 4.16 and 4.17 with an initial pH of 7.0 there was a 0.7% to 1.4% increase in pH of the treated water after *Moringa oleifera* coagulation. This indicates that the pH of the treated water was not significantly affected. This agrees with the observation of Suleyman et al, (1994), who state that *Moringa oleifera* extracts appear to have a buffering capacity and therefore the pH of the water does not alter much. From Figures 4.15 to 4.18 it was observed that the pH of the alum-treated water decreased by 11% to 21% after coagulation. It is realized that the pH of the treated water was significantly affected because of the release of hydrogen ions into the water through hydrolysis (Haarhoff and Cleasby, 1988). It is also observed from Figures 4.15 to 4.18 that the pH of the water decreases consistently with increase in alum dosage.

$$Al_2(SO_4)_3 + 6H_2O \longrightarrow 2Al(OH)_3 + 3H_2SO_4$$

$$FeCl_3 + 3H_2O \longrightarrow Fe(OH)_3 + 3HCl$$

From Figures 4.19 to 4.22, it is observed that the alkalinity of the treated water decreased by 0.9% to 2.6% after *Moringa oleifera* coagulation, whereas there was a decrease of 43% to 75% after alum coagulation. This indicates that the alkalinity of the treated water is not significantly affected after coagulation with *Moringa oleifera* but there is a drastic decrease in alkalinity with the application of alum. Haarhoff and Cleasby (1988), also indicated that there is the problem of a reaction of the alum with naturally occurring alkali substances present in the water leading to a reduction of the pH.

4.7 COMPARISON OF *MORINGA OLEIFERA* AND ALUM WITH RESPECT TO COLOUR, TURBIDITY AND SUSPENDED SOLIDS REMOVAL

Figures 4.23 to 4.26 are graphical representations of the performance of *Moringa oleifera* and alum in terms of colour reduction with initial turbidities of 105 NTU, 80 NTU, 61 NTU and 42 NTU.

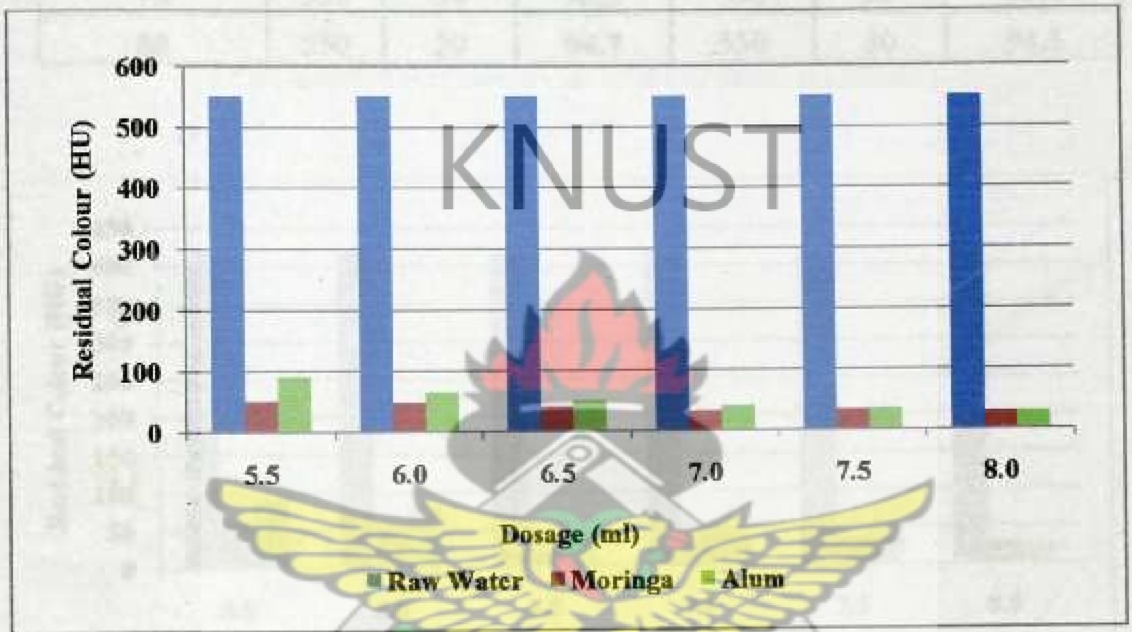

Fig. 4.23: Comparison of colours of raw water, Moringa–treated water and alum–treated water with initial turbidity of 105 NTU at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with a colour of 550 HU and initial turbidity of 105 NTU, Figure 4.23 indicates that Moringa–treated water showed a decline in colour down to between 50 HU and 29 HU. From Table 4.1 below, the colour levels obtained represents 90.9% to 94.7% removal of colour. Upon treatment with alum, however, the colour levels reduced to between 90 HU and 30 HU as observed on Figure 4.23. This represents 83.6% to 94.5% removal of colour.

Table 4.1: Percentage Removal of Colour for Moringa and Alum with initial Turbidity of 105 NTU

Dosage (ml)	Moringa			Alum		
	Initial (HU)	Final (HU)	% Removal	Initial (HU)	Final (HU)	% Removal
55	550	50	**90.9**	550	90	**83.6**
60	550	48	**91.3**	550	65	**88.2**
65	550	40	**92.7**	550	50	**90.9**
70	550	32	**94.2**	550	40	**92.7**
75	550	34	**93.8**	550	35	**93.6**
80	550	29	**94.7**	550	30	**94.5**

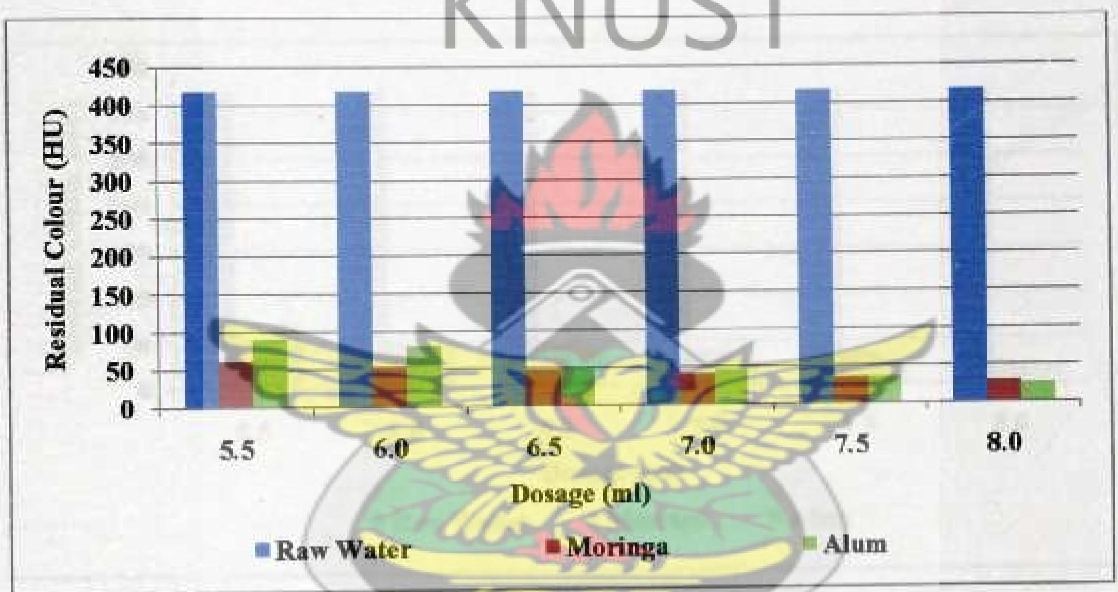

Fig. 4.24: Comparison of colours of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 80 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.24 represents the response to treatment of raw water with a colour of 417 HU and initial turbidity of 80 NTU. The colour values for the Moringa-treated water and alum-treated water range from 60 to 28 HU and 90 to 25 HU respectively. From Table 4.2, the treated water after Moringa coagulation shows 85.6% to 93.3% removal of colour. While the alum-treated water shows 78.4% to 94.0% removal of colour.

Table 4.2: Percentage Removal of Colour for Moringa and Alum with initial Turbidity of 80 NTU

Dosage (ml)	Moringa			Alum		
	Initial (HU)	Final (HU)	% Removal	Initial (HU)	Final (HU)	% Removal
55	417	60	**85.6**	417	90	**78.4**
60	417	53	**87.3**	417	80	**80.8**
65	417	47	**88.7**	417	48	**88.5**
70	417	41	**90.2**	417	45	**89.2**
75	417	35	**91.6**	417	35	**91.6**
80	417	28	**93.3**	417	25	**94.0**

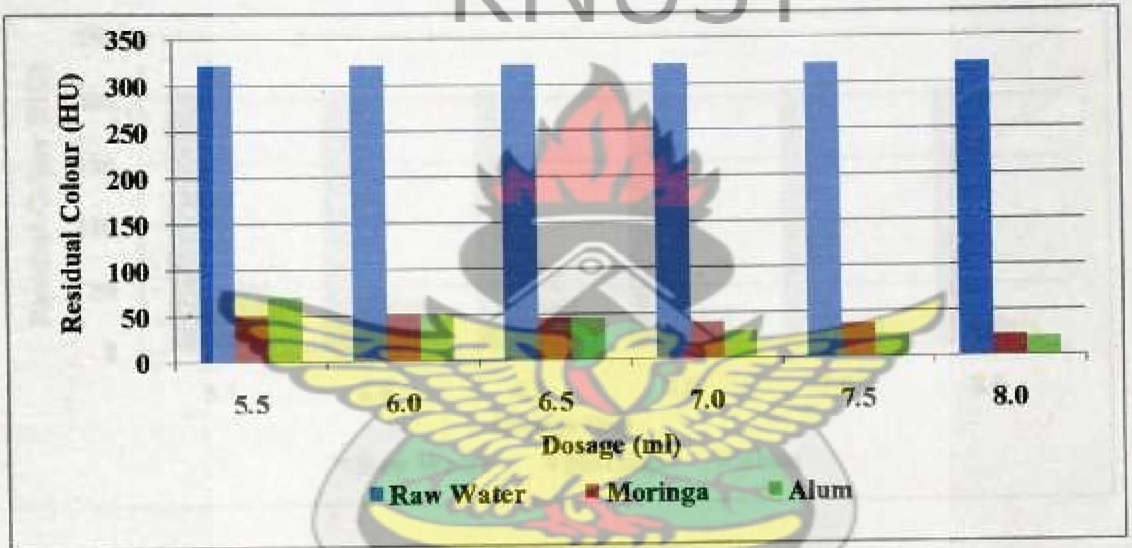

Fig. 4.25: Comparison of colours of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 61 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with a colour of 321 HU and initial turbidity of 61 NTU, Figure 4.25 indicates that Moringa–treated water showed a decrease in colour levels to between 50 HU and 24 HU. From Table 4.3, this represents 83.8% to 92.5% removal of colour. Upon treatment with alum, however, the colour levels decrease to between 70 HU and 20 HU as seen on Figure 4.25. From the table below, this represents 78.2% to 93.8% removal of colour.

Table 4.3: Percentage Removal of Colour for Moringa and Alum with initial Turbidity of 61 NTU

Dosage (ml)	Moringa			Alum		
	Initial (HU)	Final (HU)	% Removal	Initial (HU)	Final (HU)	% Removal
55	321	50	**84.4**	321	70	**78.2**
60	321	52	**83.8**	321	50	**84.4**
65	321	46	**85.7**	321	45	**86.0**
70	321	40	**87.5**	321	30	**90.7**
75	321	37	**88.5**	321	25	**92.2**
80	321	24	**92.5**	321	20	**93.8**

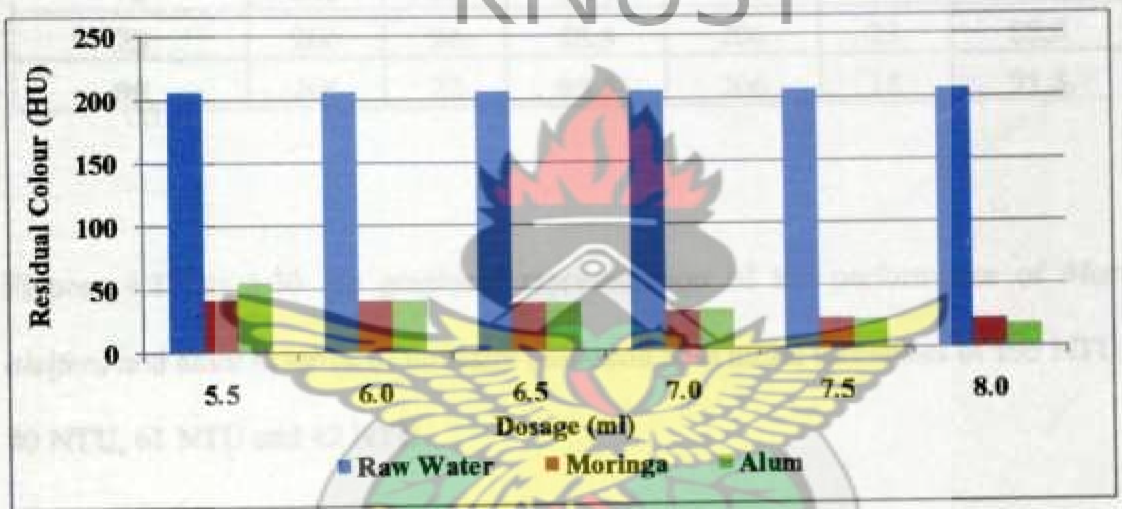

Fig. 4.26: Comparison of colours of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 42 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.26 represents changes in water after raw water with colour levels of 206 HU and initial turbidity of 42 NTU after treatment with Moringa and alum. The colour values for the Moringa-treated water and alum–treated water declined to 42 to 22 HU and 55 to 18 HU respectively. From Table 4.4, the treated water after Moringa coagulation shows 79.6% to 89.3% removal of colour whiles the treated water after alum coagulation shows 73.3% to 91.3% removal of colour.

The use of both coagulants shows a significant reduction in colour in waters of varying turbidity.

Table 4.4: Percentage Removal of Colour for Moringa and Alum with initial Turbidity of 42 NTU

Dosage (ml)	Moringa			Alum		
	Initial (HU)	Final (HU)	% Removal	Initial (HU)	Final (HU)	% Removal
55	206	42	**79.6**	206	55	**73.3**
60	206	41	**80.1**	206	40	**80.6**
65	206	38	**81.6**	206	38	**81.6**
70	206	30	**85.4**	206	32	**84.5**
75	206	24	**88.3**	206	23	**88.8**
80	206	22	**89.3**	206	18	**91.3**

Figures 4.27 to 4.30 are graphical representation of the performance of *Moringa oleifera* and alum in terms of turbidity reduction with initial turbidities of 105 NTU, 80 NTU, 61 NTU and 42 NTU.

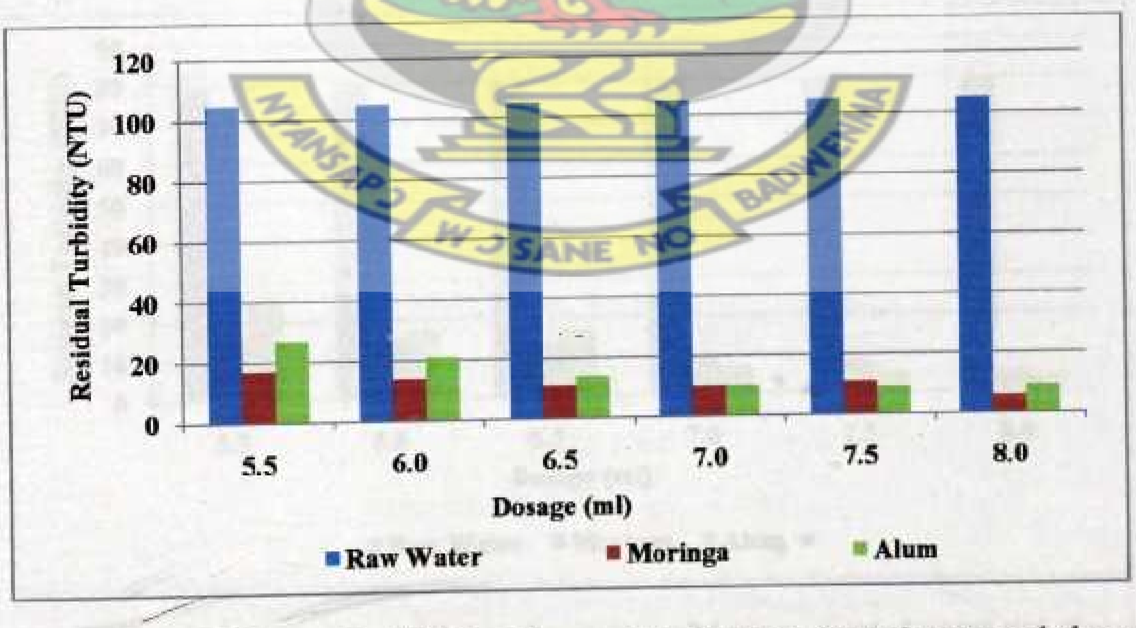

Fig. 4.27: Comparison of turbidities of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 105 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with initial turbidity of 105 NTU, Figure 4.27 indicates that Moringa–treated water showed a decrease in turbidity down to between 17 NTU and 6 NTU. From Table 4.5, this represents 83.8% to 94.3% removal of turbidity from the raw water. Upon treatment with alum, however, the turbidity decreased to between 27 NTU and 9 NTU as shown on Figure 4.27. This represents 74.3% to 91.4% removal of turbidity.

Table 4.5: Percentage Removal of Turbidity for Moringa and Alum with initial Turbidity of 105 NTU

Dosage (ml)	Moringa			Alum		
	Initial (NTU)	Final (NTU)	% Removal	Initial (NTU)	Final (NTU)	% Removal
55	105	17	**83.8**	105	27	**74.3**
60	105	14	**86.7**	105	21	**80.0**
65	105	11	**89.5**	105	14	**86.7**
70	105	10	**90.5**	105	10	**90.5**
75	105	11	**89.5**	105	9	**91.4**
80	105	6	**94.3**	105	9	**91.4**

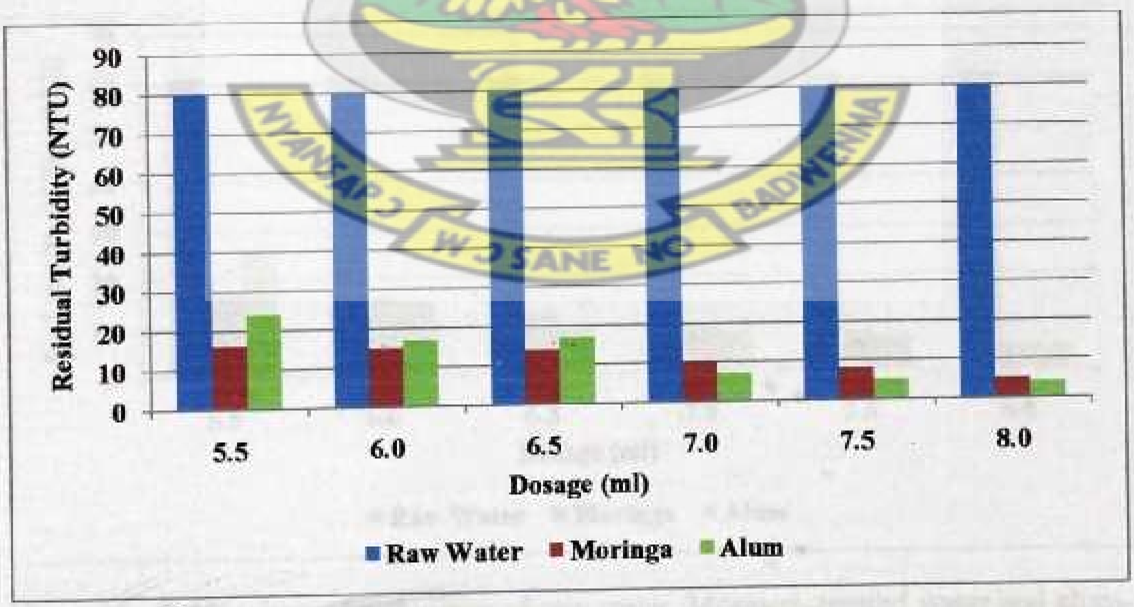

Fig. 4.28: Comparison of turbidities of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 80 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

The results of changes in the turbidity of raw water with initial turbidity of 80 NTU are shown on Figure 4.28. The turbidity values for the Moringa-treated water and alum–treated water range from 16 to 5 NTU and 24 to 4 NTU respectively. The treated water after Moringa coagulation shows 80.0% to 93.8% removal of turbidity whiles alum–treated water shows 70.0% to 95.0% removal of turbidity (Table 4.6).

Table 4.6: Percentage Removal of Turbidity for Moringa and Alum with initial Turbidity of 80 NTU

Dosage (ml)	Moringa			Alum		
	Initial (NTU)	Final (NTU)	% Removal	Initial (NTU)	Final (NTU)	% Removal
55	80	16	**80.0**	80	24	**70.0**
60	80	15	**81.3**	80	17	**78.8**
65	80	14	**82.5**	80	17	**78.8**
70	80	10	**87.5**	80	7	**91.3**
75	80	8	**90.0**	80	5	**93.8**
80	80	5	**93.8**	80	4	**95.0**

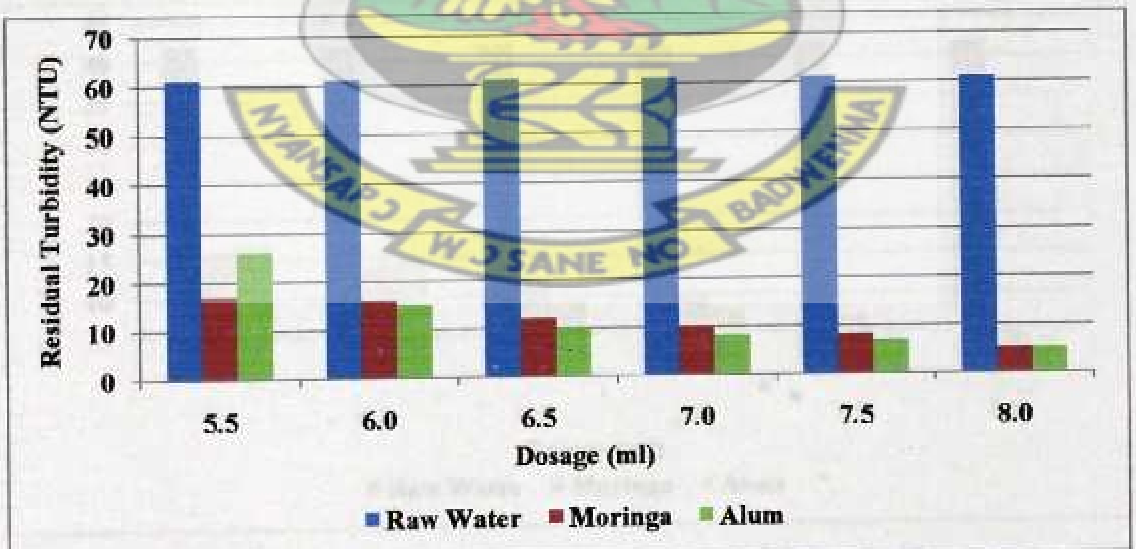

Fig. 4.29: Comparison of turbidities of raw water, Moringa–treated water and alum–treated water **with initial turbidity of 61 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with initial turbidity of 61 NTU, Figure 4.29 indicates that Moringa–treated water showed a decrease in turbidity to between 17 NTU and 5 NTU. From Table 4.7, this represents 72.1% to 91.8% removal of turbidity. Upon treatment with alum, however, the turbidity levels ranged between 26 NTU and 5 NTU as shown on Figure 4.29 representing a 57.4% to 91.8% removal of turbidity.

Table 4.7: Percentage Removal of Turbidity for Moringa and Alum with initial Turbidity of 61 NTU

Dosage (ml)	Moringa			Alum		
	Initial (NTU)	Final (NTU)	% Removal	Initial (NTU)	Final (NTU)	% Removal
55	61	17	**72.1**	61	26	**57.4**
60	61	16	**73.8**	61	15	**75.4**
65	61	12	**80.3**	61	10	**83.6**
70	61	10	**83.6**	61	8	**86.9**
75	61	8	**86.9**	61	7	**88.5**
80	61	5	**91.8**	61	5	**91.8**

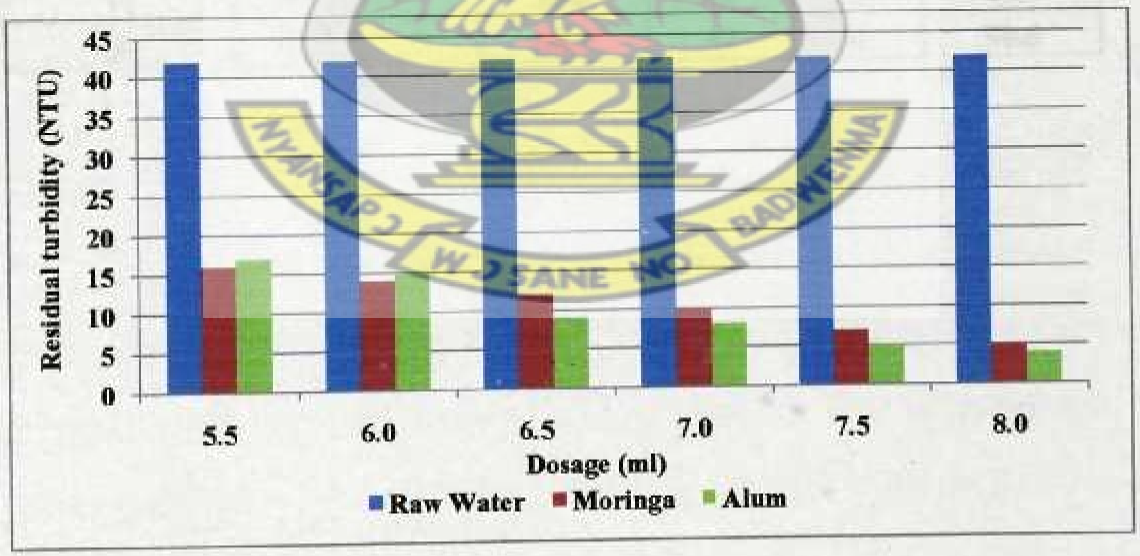

Fig. 4.30: Comparison of turbidities of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 42 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.30 represents changes in raw water with initial turbidity of 42 NTU. The turbidity values for the Moringa-treated water and alum–treated water range from 16 to 5 NTU and 17 to 4 NTU respectively. The treated water after Moringa coagulation shows 61.9% to 88.1% removal of turbidity whiles the treated water after alum coagulation shows 59.5% to 90.5% removal of turbidity (Table 4.8).

The use of both coagulants shows a significant reduction in turbidity in waters of varying turbidity.

Table 4.8: Percentage Removal of Turbidity for Moringa and Alum with initial Turbidity of 42 NTU

Dosage (ml)	Moringa			Alum		
	Initial (NTU)	Final (NTU)	% Removal	Initial (NTU)	Final (NTU)	% Removal
55	42	16	**61.9**	42	17	**59.5**
60	42	14	**66.7**	42	15	**64.3**
65	42	12	**71.4**	42	9	**78.6**
70	42	10	**76.2**	42	8	**81.0**
75	42	7	**83.3**	42	5	**88.1**
80	42	5	**88.1**	42	4	**90.5**

Figures 4.31 to 4.34 are graphical representation of the performance of *Moringa oleifera* and alum in terms of suspended solids reduction with initial turbidities of 105 NTU, 80 NTU, 61 NTU and 42 NTU.

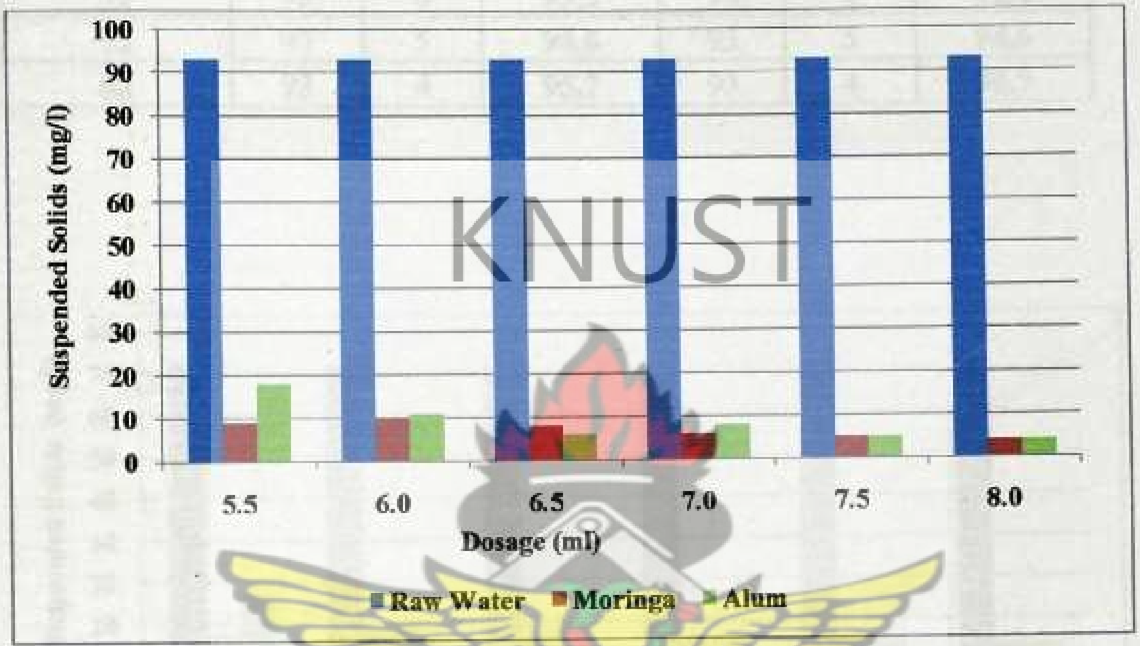

Fig. 4.31: Comparison of suspended solids of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 105 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with suspended solids of 93 mg/l and initial turbidity of 105 NTU, Figure 4.31 indicates that suspended solids in Moringa–treated water decreased to between 9 mg/l and 4 mg/l. This represents 90.3% to 95.7% removal of suspended solids. Upon treatment with alum, the suspended solids ranged between 18 mg/l and 4 mg/l as shown on Figure 4.31. This represents 80.6% to 95.7% removal of suspended solids (Table 4.9).

Table 4.9: Percentage Removal of Suspended Solids for Moringa and Alum with initial Turbidity of 105 NTU

Dosage (ml)	Moringa			Alum		
	Initial (mg/l)	Final (mg/l)	% Removal	Initial (mg/l)	Final (mg/l)	% Removal
55	93	9	**90.3**	93	18	**80.6**
60	93	10	**89.2**	93	11	**88.2**
65	93	8	**91.4**	93	6	**93.5**
70	93	6	**93.5**	93	8	**91.4**
75	93	5	**94.6**	93	5	**94.6**
80	93	4	**95.7**	93	4	**95.7**

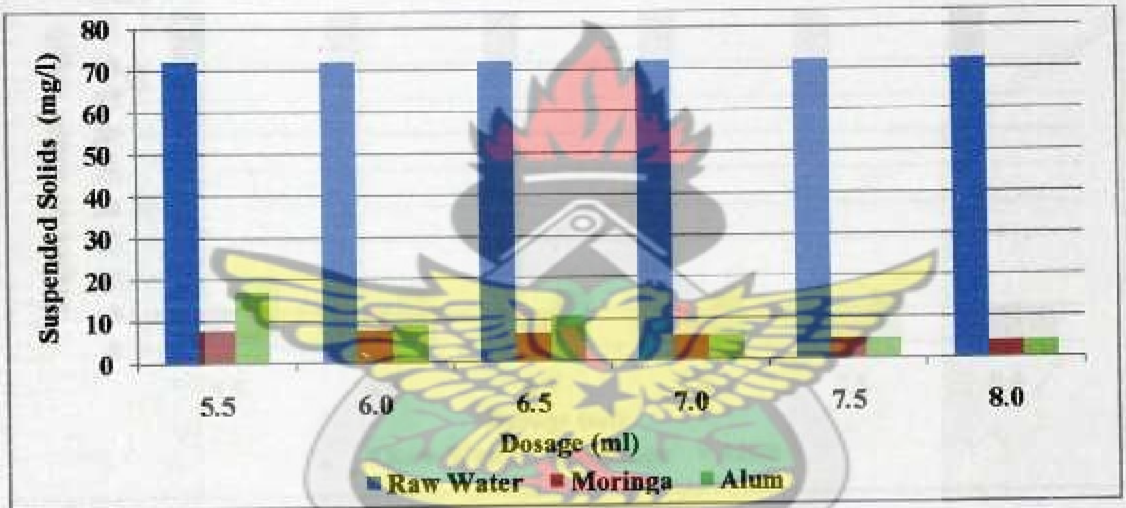

Fig. 4.32: Comparison of suspended solids of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 80 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.32 represents the behavior of raw water with suspended solids of 72 mg/l and initial turbidity of 80 NTU. The suspended solids values for the Moringa-treated water and alum–treated water range from 8 to 4 mg/l and 17 to 4 mg/l respectively. From Table 4.10, the treated water after Moringa coagulation shows 88.9% to 94.4% removal of suspended solids whiles alum–treated water shows a 76.4% to 94.4% removal of suspended solids.

Table 4.10: Percentage Removal of Suspended Solids for Moringa and Alum with initial Turbidity of 80 NTU

Dosage (ml)	Moringa			Alum		
	Initial (mg/l)	Final (mg/l)	% Removal	Initial (mg/l)	Final (mg/l)	% Removal
55	72	8	**88.9**	72	17	**76.4**
60	72	8	**88.9**	72	9	**87.5**
65	72	7	**90.3**	72	11	**84.7**
70	72	6	**91.7**	72	6	**91.7**
75	72	5	**93.1**	72	5	**93.1**
80	72	4	**94.4**	72	4	**94.4**

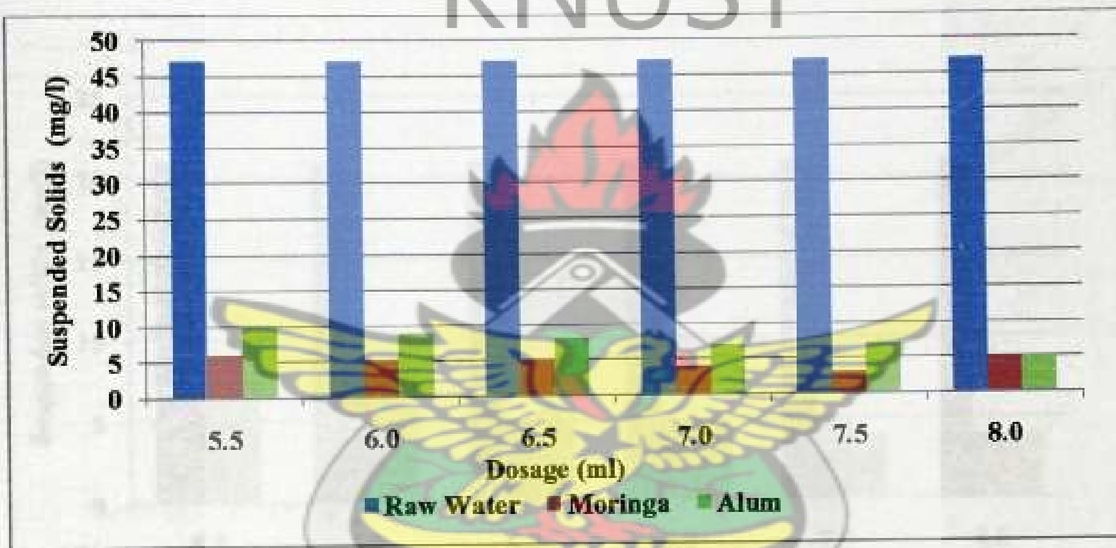

Fig. 4.33: Comparison of suspended solids of raw water, Moringa–treated water and alum–treated water with initial turbidity of 61 NTU at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with suspended solids of 47 mg/l and initial turbidity of 61 NTU, Figure 4.33 indicates that Moringa–treated water showed a decrease in suspended solids to between 3 mg/l and 6 mg/l. From Table 4.11, this represents 87.2% to 93.6% removal of suspended solids. Upon treatment with alum, the levels of suspended solids ranged between 5 mg/l and 10 mg/l as shown on Figure 4.29. This represents 78.7% to 89.4% removal of suspended solids.

Table 4.11: Percentage Removal of Suspended Solids for Moringa and Alum with initial Turbidity of 61 NTU

Dosage (ml)	Moringa			Alum		
	Initial (mg/l)	Final (mg/l)	% Removal	Initial (mg/l)	Final (mg/l)	% Removal
55	47	6	**87.2**	47	10	**78.7**
60	47	5	**89.4**	47	9	**80.9**
65	47	5	**89.4**	47	8	**83.0**
70	47	4	**91.5**	47	7	**85.1**
75	47	3	**93.6**	47	7	**85.1**
80	47	5	**89.4**	47	5	**89.4**

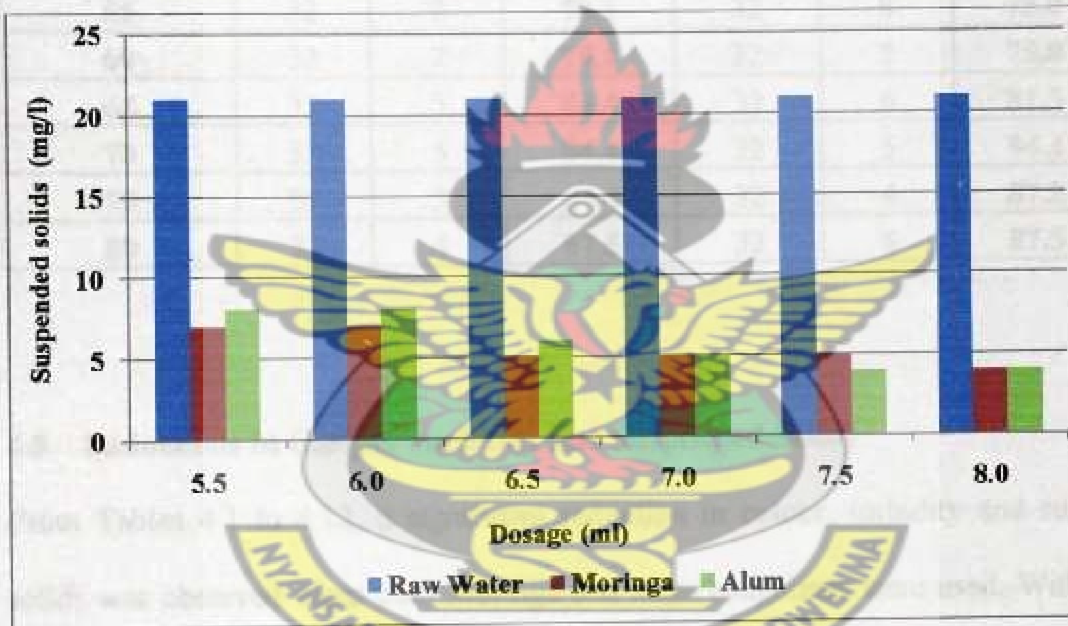

Fig. 4.34: Comparison of suspended solids of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 42 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.34 represents changes in raw water suspended solids of 93 mg/l and initial turbidity of 42 NTU. The suspended solids values for the Moringa-treated water and alum–treated water range from 7 to 4 mg/l and 8 to 4 mg/l respectively. The treated water after Moringa coagulation shows 78.1% to 87.5% removal of suspended solids whiles the treated water after alum coagulation shows 75.0% to 87.5% removal of suspended solids (Table 4.12).

The use of both coagulants shows a significant reduction in suspended solids in waters of varying turbidity.

Table 4.12: Percentage Removal of Suspended Solids for Moringa and Alum with initial Turbidity of 42 NTU

Dosage (ml)	Moringa			Alum		
	Initial (mg/l)	Final (mg/l)	% Removal	Initial (mg/l)	Final (mg/l)	% Removal
55	32	7	**78.1**	32	8	**75.0**
60	32	7	**78.1**	32	8	**75.0**
65	32	5	**84.4**	32	6	**81.3**
70	32	5	**84.4**	32	5	**84.4**
75	32	5	**84.4**	32	4	**87.5**
80	32	4	**87.5**	32	4	**87.5**

4.8 Reductions in Colour, Turbidity and Suspended Solids

From Tables 4.1 to 4.12, a significant reduction in colour, turbidity and suspended solids was observed when both Moringa and alum coagulants were used. With a high raw water turbidity of 105 NTU from Table 4.1, the percentage removal of colour by *Moringa oleifera* was 90.9% to 94.7%. The minimum percentage removal of 90.9% registered by Moringa was slightly higher than that registered by alum which is 83.6%. The maximum colour removal was statistically not different. Similarly the minimum percentage removal of turbidity by *Moringa oleifera* of 83.8 was slightly higher than that registered by alum which is 74.3% (Table 4.5).

Also with a low raw water turbidity of 80, 61 and 42 NTU, the minimum percentage removal of colour by *Moringa oleifera* of 79.6% was higher than that registered by alum of 73.3%. Similarly the minimum percentage removal of turbidity by *Moringa oleifera* of 61.9% was also higher than that registered by alum which is 57.4%. However with a low raw water turbidity of 80, 61 and 42 NTU, the maximum percentage removal of colour by *Moringa oleifera* of 93.3% was lower than that registered by alum of 94.0%. The turbidity readings showed a similar trend as observed with the colour. The percentage removal of turbidity by *Moringa oleifera* was 93.8% which is lower than that registered by alum of 95.0%.

For low initial turbidity, coagulation performance of alum was better than that of Moringa. This observation agrees with earlier work done by Sutherland et al., (1990) and Muyibi and Evison, (1995), who also worked on low turbidity waters. In such cases the Moringa coagulant may be used as a coagulant aid. For all experimental conditions, colour, turbidity and suspended solids removal efficiency of *Moringa oleifera* increased as initial turbidity of water sample increased. The highest turbidity removal efficiencies were recorded for water sample with very high initial turbidity. Muyibi and Evison, (1995), documented that, at the optimum concentration of *Moringa oleifera* residual turbidities decreased and removal turbidities increased with increasing initial turbidity. Turbidity removal up to 98.5% was recorded for a water sample with high initial turbidity of 600 NTU (Muyibi and Evison, 1995).

Increase in suspended particles available for adsorption and inter-particle bridge formation in water sample with higher initial turbidity may contribute to higher efficiency in turbidity removal (Birkner and Morgan, 1968). The percentage removal of colour, turbidity and suspended solids at the lower dosages of 55 ml and 60 ml were very higher for *Moringa oleifera* than alum. The advantage here is that there is a wide dosage range over which effective treatment can be achieved and maintained by *Moringa oleifera*. It is also observed from Tables 4.1 to 4.12 that the percentage removal of colour, turbidity and suspended solid by Moringa and alum increase with increasing dosage of alum and Moringa.

4.9 COMPARISON OF *MORINGA OLEIFERA* AND ALUM WITH RESPECT TO HARDNESS

Figures 4.35 to 4.39 are graphical representations of the performance of *Moringa oleifera* and alum in terms of hardness with initial turbidities of 105 NTU, 80 NTU, 61 NTU and 42 NTU.

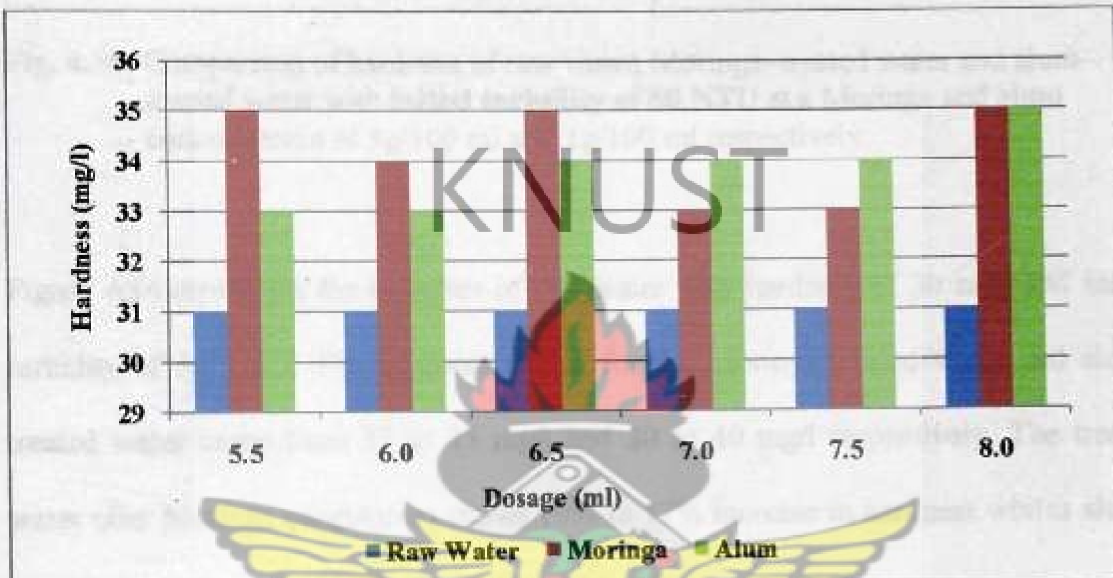

Fig. 4.35: Comparison of hardness of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 105 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with hardness of 31 mg/l and initial turbidity of 105 NTU, Figure 4.35 indicates that Moringa–treated water experiences an increase in hardness to between 33 mg/l and 35 mg/l. This represents an increment of 6.5% to 13%. Similarly, upon treatment with alum, the increase in hardness ranged between 33 mg/l and 35 mg/l just as was experienced in the case of Moringa. The Moringa treatment did not show consistency in the resultant hardness but the alum treatment showed an increase in hardness with increasing alum dosage.

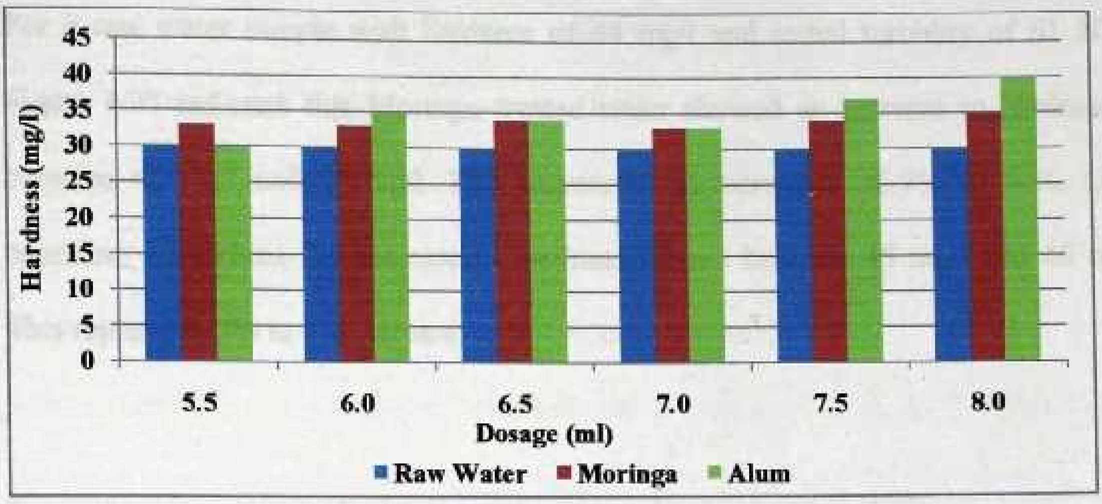

Fig. 4.36: Comparison of hardness of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 80 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.36 represents the behavior of raw water with hardness of 30 mg/l and initial turbidity of 80 NTU. The hardness values for the Moringa-treated water and alum-treated water range from 33 to 35 mg/l and 30 to 40 mg/l respectively. The treated water after Moringa coagulation shows 10% to 17% increase in hardness whiles alum-treated water shows 33% increase in hardness.

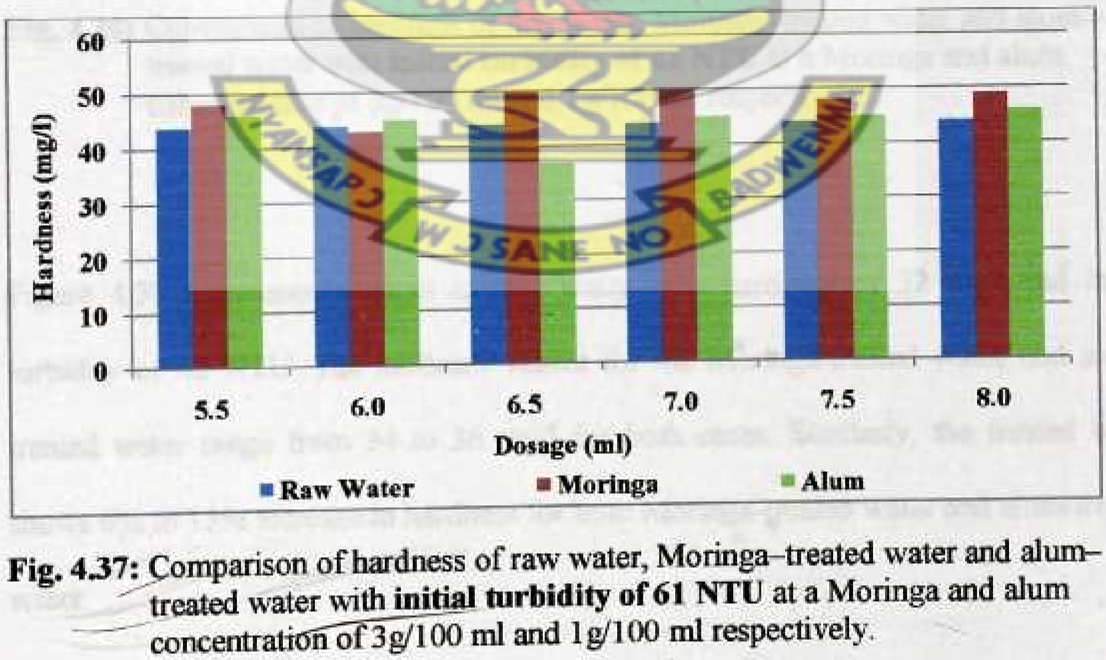

Fig. 4.37: Comparison of hardness of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 61 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with hardness of 44 mg/l and initial turbidity of 61 NTU, Figure 4.37 indicates that Moringa–treated water showed an increase in hardness to between 48 mg/l and 50 mg/l. This represents an increment of 9% to 14%. Upon treatment with alum, the increase in hardness ranged between 45 mg/l and 46 mg/l. This represents 2% to 5% increase.

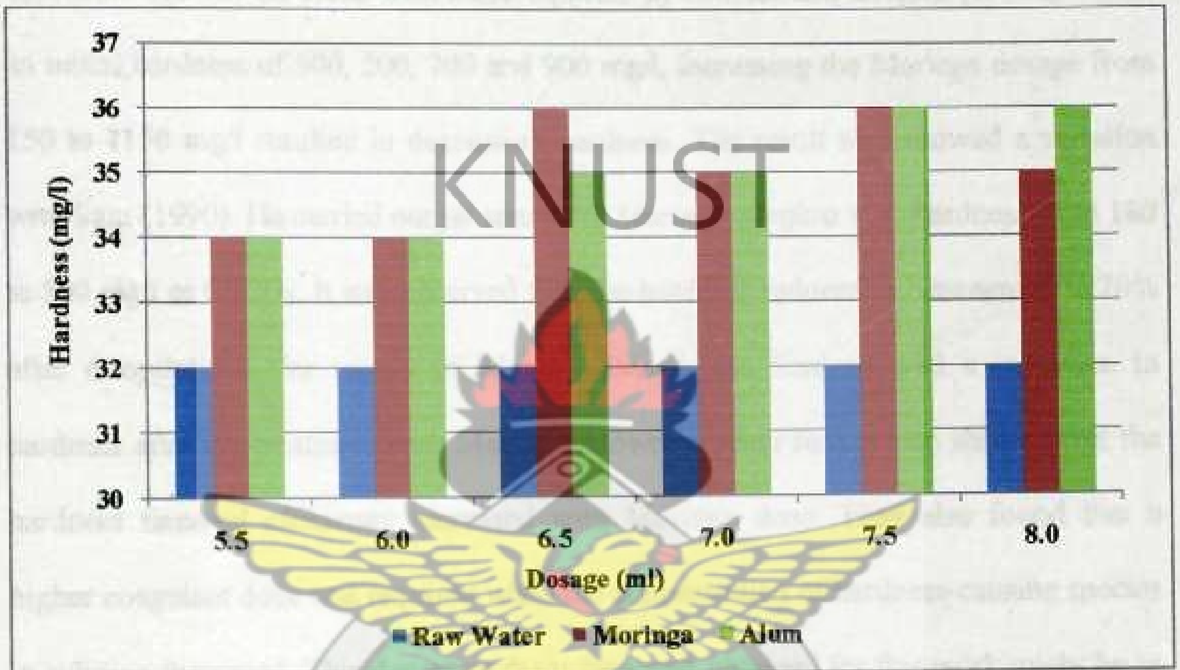

Fig. 4.38: Comparison of hardness of raw water, Moringa–treated water and alum–treated water with **initial turbidity of 42 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

Figure 4.38 represents changes in raw water with hardness of 32 mg/l and initial turbidity of 42 NTU. The hardness values for the Moringa-treated water and alum–treated water range from 34 to 36 mg/l for both cases. Similarly, the treated water shows 6% to 13% increase in hardness for both Moringa-treated water and alum-treated water.

4.10 Hardness

Figures 4.35 to 4.38 show 6% to 17% increase in hardness of the treated water after *Moringa oleifera* coagulation with a similar increase of 2% to 33% after alum coagulation. Although the maximum hardness value of 50 mg/l recorded by the *Moringa oleifera* was within the maximum desirable concentration of 100 mg/l $CaCO_3$, the result was not the same with those reported by Muyibi and Evison, (1995a). With an initial hardness of 300, 500, 700 and 900 mg/l, increasing the Moringa dosage from 150 to 1150 mg/l resulted in decreasing hardness. The result also showed a variation with Sani (1990). He carried out jar tests with *Moringa oleifera* with hardness from 180 to 300 mg/l as $CaCO_3$. It was observed that, the hardness reduced to between 60 to 70% after coagulation. The results of Muyibi, Evison and Sani showed a reduction in hardness after the treatment with Moringa. However, their results also showed that the hardness removal efficiency increased with Moringa dose. They also found that a higher coagulant dose was required when the concentration of hardness-causing species in solution increased. This departure from the result obtained for this work might be as a result of low values of hardness of raw water used for this experiment.

4.11 COMPARISON OF *MORINGA OLEIFERA* AND ALUM WITH RESPECT TO WEIGHT OF SLUDGE PRODUCED

Figures 4.39 to 4.42 are graphical representations of the sludge produced by *Moringa oleifera* and alum with initial turbidities of 105 NTU, 80 NTU, 61 NTU and 40 NTU.

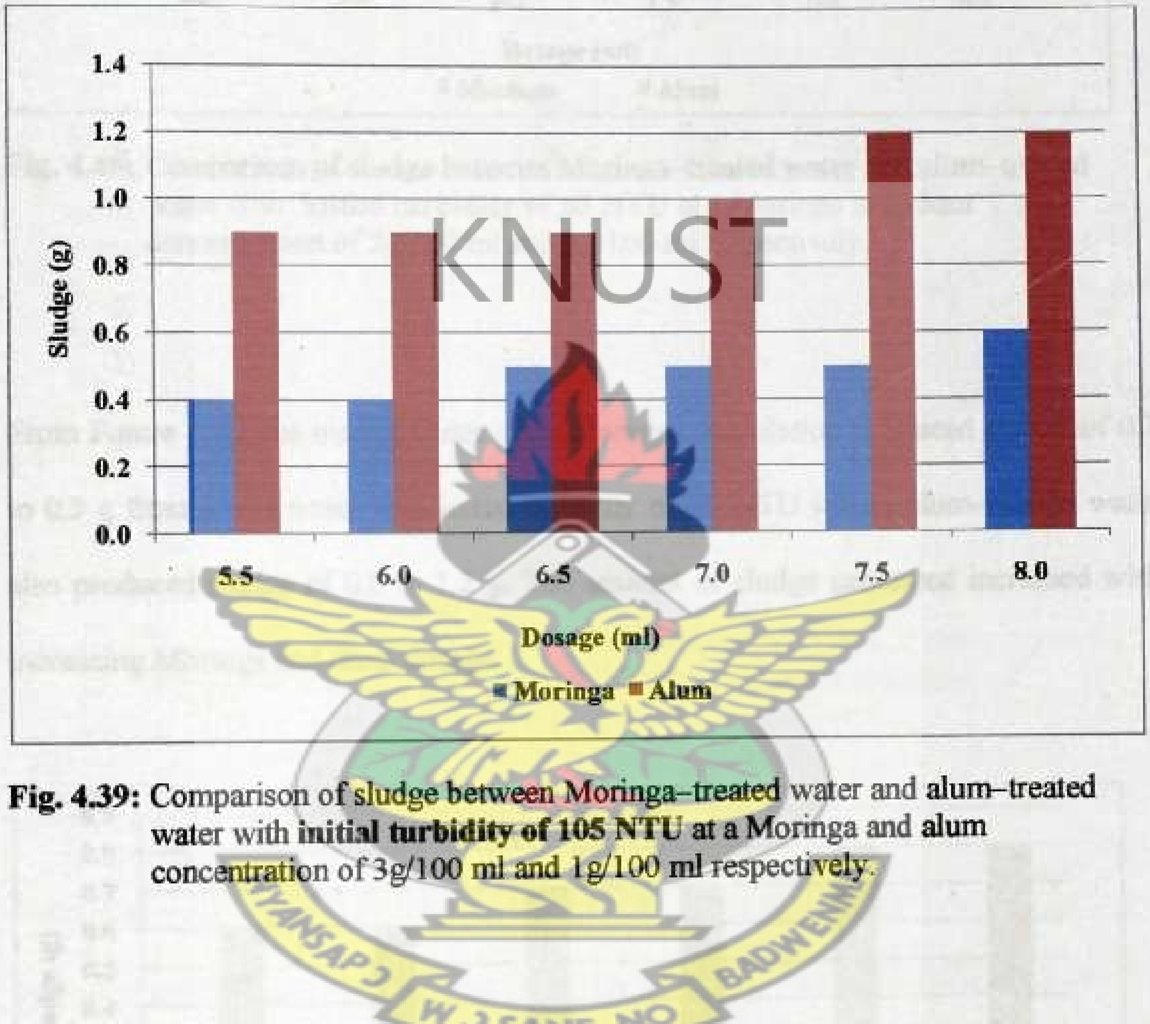

Fig. 4.39: Comparison of sludge between Moringa–treated water and alum–treated water with **initial turbidity of 105 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with initial turbidity of 105 NTU, Figure 4.39 indicates the amount of sludge generated after Moringa treatment ranged between 0.4 to 0.6 g. The amount of sludge generated increased with increasing Moringa dosage. Upon treatment with alum more sludge of 0.9 to 1.2 g was produced. Similarly, the amount of sludge produced increased with increasing alum dosage.

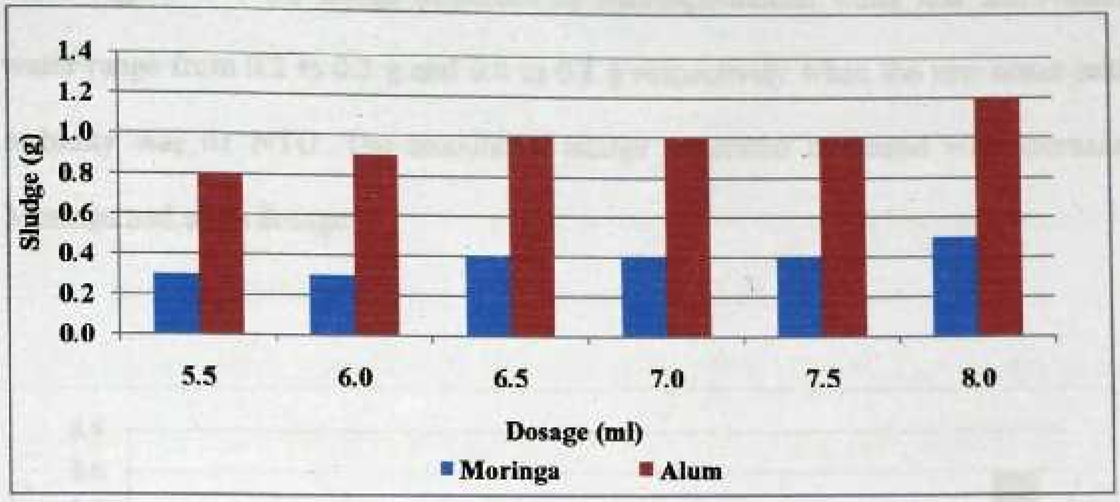

Fig. 4.40: Comparison of sludge between Moringa–treated water and alum–treated water with **initial turbidity of 80 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

From Figure 4.40, the treated water after Moringa coagulation produced sludge of 0.3 to 0.5 g from a raw water with initial turbidity of 80 NTU whiles alum–treated water also produced sludge of 0.8 to 1.2 g. The amount of sludge generated increased with increasing Moringa and alum dosage.

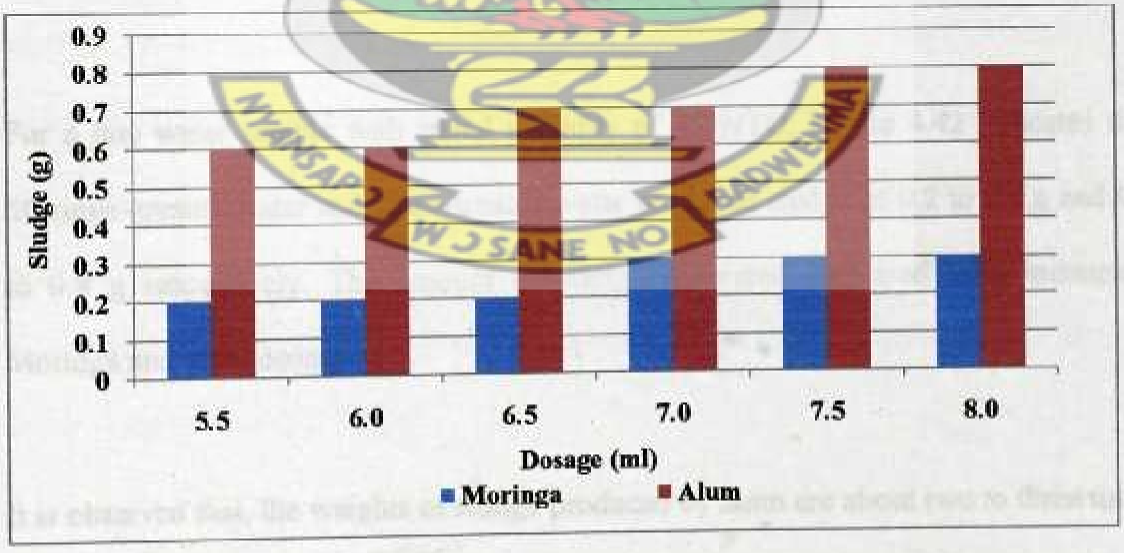

Fig. 4.41: Comparison of sludge between Moringa–treated water and alum–treated water with **initial turbidity of 61 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

From Figure 4.41 the sludge produced by Moringa-treated water and alum-treated water range from 0.2 to 0.3 g and 0.6 to 0.8 g respectively when the raw water initial turbidity was 61 NTU. The amount of sludge generated increased with increasing Moringa and alum dosage.

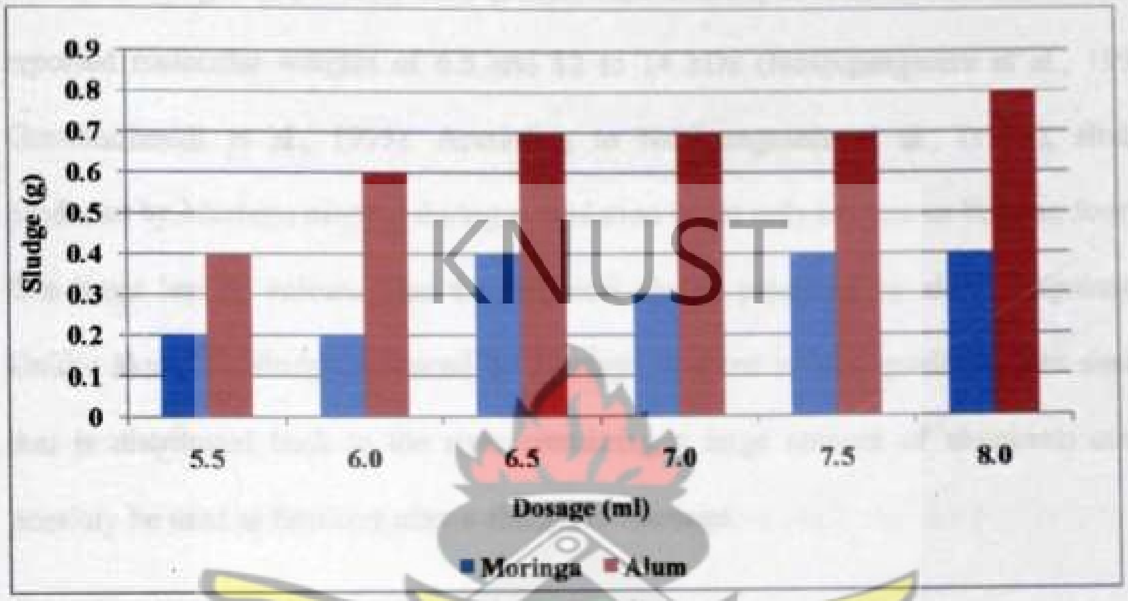

Fig. 4.42: Comparison of sludge between Moringa-treated water and alum-treated water with **initial turbidity of 42 NTU** at a Moringa and alum concentration of 3g/100 ml and 1g/100 ml respectively.

For a raw water sample with initial turbidity of 42 NTU, Figure 4.42 indicates that Moringa-treated water and alum-treated water produced sludge of 0.2 to 0.4 g and 0.4 to 0.8 g respectively. The amount of sludge generated increased with increasing Moringa and alum dosage.

It is observed that, the weights of sludge produced by alum are about two to three times more in weight than that for *Moringa oleifera* coagulation.

4.12 Weight of Sludge Produced by *Moringa oleifera* and Alum

Figures 4.39 to 4.42 produced sludge of 0.2 to 0.4 g and 0.4 to 1.2 g for Moringa and alum respectively. It was observed that, the weight of sludge produced by alum was about two to three times more in weight than that for *Moringa oleifera* coagulation. The lower weight of sludge produced after application of Moringa may be due to its low molecular weight of about 13 kDa (Muyibi and Evison, 1995b). Earlier studies have reported molecular weights of 6.5 and 12 to 14 kDa (Ndabigengesere et al., 1995; Gassenschmidt et al., 1995). According to Ndbigengesere et al., (1995), sludge produced by *Moringa oleifera* during coagulation is not only innocuous but also four to five times less in volume than the chemical sludge produced by alum coagulation. Unlike alum, the sludge produced by *Moringa oleifera* is biodegradable. The sludge that is distributed back to the river containing a large amount of aluminum could possibly be used as fertilizer after a change to Moringa.

4.13 Settling Time

From Figure 4.1 to 4.8 an average settling time of 2 hours was obtained for *Moringa oleifera* as compared to 1 hour for alum (Suleyman et al, 1994). According to Suleyman et al, (1994), the flocs formed from *Moringa oleifera* are generally pin-like and light and therefore settle slowly. Coagulation of water with *Moringa oleifera* consists of adsorption and charge neutralization of suspended solids while that with alum consists of adsorption and inter-particle bridging of suspended solids resulting in larger flocs which settle faster.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Moringa oleifera shows good coagulation properties, and has many advantages compared to alum. It does not affect the pH and alkalinity of the water. This advantage of *Moringa oleifera* over alum would be an asset, especially in developing countries where savings could be made on importation of chemicals used for pH correction. The *Moringa oleifera* and alum increased the hardness of the treated water.

The efficiency of turbidity, colour and suspended solids removal by *Moringa oleifera* is comparable to that of alum. The reductions observed for Moringa were 61.9% to 94.3% for turbidity, 79.6% to 94.7% for colour and 78.1% to 95.7% for suspended solids. For alum, the reductions were 59.5% to 91.4% for turbidity, 73.3% to 94.5% for colour and 75.0% to 95.7% for suspended solids. Moringa did not show the same efficiency in turbidity removal, colour reduction and suspended solids removal when the initial turbidity was low. However, it was more efficient than alum when the initial turbidity was high. It is also observed that the percentage removal of colour, turbidity and suspended solids at the lower dosages of 55 ml and 60 ml were very higher for *Moringa oleifera* than alum. The advantage here is that there is a wide dosage range over which effective treatment can be achieved and maintained by *Moringa oleifera*. Also the percentage removals of colour, turbidity and suspended solids by Moringa and alum increase with increasing dosage of alum and Moringa.

It was observed that, the weight of sludge produced by alum was two to three times more in weight than that for *Moringa oleifera* coagulation. This is another advantage because fewer resources will be required in the treatment and disposal of sludge from

Moringa oleifera. Flocs formed after coagulation with *Moringa oleifera* are pin-like and light. They therefore settle slowly. The average settling time was 2 hours. This is two times that of alum. The optimum *Moringa oleifera* concentration for the treatment of water was 3g/100 ml.

5.2 RECOMMENDATIONS

Further studies need also be done regarding the impact of raw water pH on the efficiency of Moringa, since the water used in this study had a very narrow pH range and the efficiency of most coagulants is pH dependent.

The optimum dosage of *Moringa oleifera* should be investigated for different levels of turbidity with different Moringa concentrations.

An extensive research should be conducted on the cost analysis of planting, cultivation and assessment of the yield of *Moringa oleifera* seeds on a large scale.

Further studies need to be carried out in order to provide insight into the interaction between the suspension from *Moringa oleifera* seeds and the constituents of raw water.

The Moringa tree is not known by most local communities and for it to be known there is the need to intensify extension services so that local communities and water supply firms will be sensitized about the importance and the use of this tree. Collaboration and networking should be encouraged among key institutions, researchers, District Councils, the private sector, NGOs, and local communities. There is need also to provide incentives to participating institutions for growing and using *Moringa oleifera* in water treatment.

REFERENCES

Akhtar M., Hasany S. M., Bhanger M. I., Iqbal S., (2006). **Absorption potential of *Moringa oleifera* pods for the removal of organic pollutants from aqueous solutions.** Journal of Hazardous Material.

Al-Khalili, R. S., Sutherland, J. P. and Folkard, G. K., (1997). **Filtration with a Natural Coagulant.** Water and Sanitation for All: Partnerships and Innovations, Proceedings of the 23rd WEDC Conference, Durban, South Africa, pp. 143-145.

Al-Samawi, A. A. and Shokrala, E.M., (1996). **An investigation into indigenous natural coagulant.** Journal Environmental Science Health, Vol.31, No.8, pp.1881-1897.

APHA, AWWA, WPCF, (1992). **Standard Methods for the Examination of Water and Wastewater**, 18th Edition. American Public Works Association, American Water Works Association and World Pollution Control Federation, Washington, D.C. Mcgraw-Hill Inc.

APHA, (1998). **Standard Methods for the Examination of Water and Wastewater,** 20th edition. American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington, D. C. Mcgraw-Hill Inc.

Arnoldsson, E. and Bergman M., (2007). **Assessment of drinking water treatment using *Moringa oleifera* natural coagulant.** A minor field study in Maputo, Mozambique. MSc. thesis, Department of Water Resources Engineering, Lund University, Sweden.

AWWA, (1999). **Water quality and treatment:** A handbook of community water supplies. 5th ed. Letterman, R. D. (Technical Editor). Published by McGraw-Hill, Inc.

Berger, M. R., Hebs, M., Jahn, S. A. A. and Schmahi, D., (1984). **Toxicological Assessment of Seeds from *Moringa oleifera* and *Moringa stenopetala*: two efficient primary coagulants for domestic water treatment of tropical waters.** East African Medical Journal, pp. 712 – 716.

Bhole A. G., (1995). **Relative evaluation of a few natural coagulants.** Journal SRT-Aqua, Vol.44, No.6, pp.284-290.

Bina, B., (1991). **Investigations into the use of natural plant coagulants in the removal of bacteria and bacteriophage from turbid waters.** Ph. D thesis, University of Newcastle upon Tyne.

Birkner, F. B and Morgan, J. J., (1968). **Polymer flocculation kinetics of dilute colloidal suspension.** Journal of American Water Works Association, No.2, pp.175-191.

Chung, Y.-C., Wang, H.-L., chan, Y.M. and Li,S.-L., (2003). **Effect of abiotic factors on antimicrobial activity of clutosan against waterborne pathogens.** Bioresources Technology, Vol.88, pp.279-284.

Conley, W. R., (1961). **Experience with anthracite-sand filters.** Journal of American Water Works Association, Vol.53, No.12, pp.1473-1478.

Davikaran, R. and Pillai, V. N. S., (2001). **Fluccolation of kaolinite suspension in water by chitosan**. Water Research, Vol.35 No.16, pp.3904-3908.

Diaz, A., Rincon, N., Escorihuela, A., Fernandez, N., Chacin, E. and Forster, C. F., (1999). **A preliminary evaluation of turbidity removal by natural coagulants indigenous to Venezuela.** Process Biochemistry, Vol.35, pp.391-395.

Doerr Berth, (2005). **Moringa Water Treatment.**
An ECHO technical note, ECHO, USA,
http://www.echotech.org/mambo/images/DocMan/MorWaterTreat.pdf
(Retrieved 15th of December 2007)

Duan, J. and Gregory, J., (2003). **Coagulation by hydrolysing metal salts.** Advances in coloidal and Interface science, pp.475-502.

Eckenfelder, W. W., (2000). **Industrial Water Pollution Control.** 3rd Edition. Mcgraw-Hill Series in Water Resources and Environmental Engineering.

Eilert, U., Wolters, B. and Nahrstedt, (1981). **The antibiotic principle of *Moringa oleifera* and *Moringa stenopetala*.** Planta Medical, Vol.42, pp.55-61.

Encarta ® Microsoft ® Encyclopedia (2006). © 1993-2004 Microsoft Corporation.

Folkard, G. K., Sutherland, J. P and Grant, W. P., (1989). **Optimization of the use of Natural Coagulants for Water Purification.** Technical Report No. R4254. University of Leicester.

Folkard, G. K., Sutherland, J.P., Mtawali, M. A. and Grant, W. D., (1994). ***Moringa oleifera* as a natural coagulant in affordable water supply and sanitation,** J. Pickford et al., eds. Intermediate Technology Publications, pp. 295-299.

Gassenschmidt, U., Jany, K. D., Tauscher, B. and Niebergal, H., (1995). **Isolation and Characterization of a flocculation protein from *Moringa oleifera*.** Biochemica et Biophysics Acta-General Subjects, Vol. 1234, No. 3, pp. 447-481.

Goh, C.W., (2005). **Effect of room temperature on coagulation performance of Moringa oleifera seeds.** B.Sc. Dissertation, Faculty of Engineering, Universiti Putra Malaysia.

Gregory, J., (1991). **Stability and flocculation of colloidal particles.** Effluent and water treatment journal, Vol.17, pp. 641-651.

Guibal, E., Van Vooren, M., Dempsey, B. A., and Roussy, J., (2006). **A review of the use of chitosan for the removal of particulate and dissolved contaminants.** Separation Science and Technology, Vol.41, No.11, pp. 2487–2514.

Haarhoff, J. and Cleasby, J. L., (1988). **Comparing aluminum and iron coagulants for in-line filtration of cold waters.** Journal of American Water Work Association Vol.80, pp.168–175.

Jahn, S. A. A. and Dirar, H., (1979). **Studies on natural water coagulants in Sudan, with special reference to *moringa oleifera* seeds**. Water S.A., Vol. 6, pp. 43-50.

Jahn, S. A. A., (1986). **Proper use of African natural coagulants for rural water supplies-research in Sudan and a guide to new projects.** GTZ manual No.191.

Jahn, S. A. A., (1988). **Using *Moringa oleifera* seeds as coagulant in developing countries.** Journal of American Water Work Association, No.6, pp. 43-50.

Jahn, S. A. A., (1989). **'Simplified water treatment technologies for rural areas'**, GATE, GTZ, Issue 1, Eschborn.

Jahn, S. A. A., (2001). **Drinking water from Chinese rivers: Challenges of clarification.** Journal water Supply Research Technology, Vol.50, pp.15-27.

Kaser F., Werner C. and Nahayo D., (1990). **Rural water treatment using *Moringa oleifera* seeds as coagulant. Natural Resources Development**, Institute of Scientific Co-operation, Tubingen, Germany. Vol. 33, pp. 33-47.

Lamer, V. K. and Healy, T. W., (1963). **The adsorption flocculation reactions of macromolecules at the solid-liqiud interface.** Revised Pure and Applied chemistry, Vol.13, pp. 112-122.

Leicester University Engineering Department, (1994). **Optimisation of the use of natural coagulants for water clarification.** Final Report Phase 1. ODA Project No.4254.

Lui, X. F., Guan, Y.L., Yang, D. Z., Li, Z. and Yoa, K. D., (2000). **Antibacterial action of chitosans and carboxymethylated chitosan** . Journal of Applied Polymer Science, Vol.79, No.7, pp1324-1335.

Madsen, M., Schlundt, J. and Omer, El Fadil, E., (1987). **Effect of water coagulated by seeds of *Moringa oleifera* on bacterial concentrations.** Journal of Tropical Medicine and Hygiene, *Vol.90*, pp.101-109.

Muyibi, S. A. and Evision, L. M., (1995a). ***Moringa oleifera* seeds for softening hardwater.** Water Research, Vol.29, No.4, pp. 1099-1104.

Muyibi, S. A. and Evision, L. M., (1995b). **Optimizing physical parameter affecting coagulation of turbid water with *Moringa oleifera* Seeds.** Water Research.Vol.29, No.12, pp. 2689-2695.

Muyibi, S. A. and Okufu, C. A., (1995). **Coagulation of low turbidity surface water with *Moringa oleifera* seeds.** Int. J. Environ. Stud. Vol.48, pp.263–273.

Ndabigengesere, A., Narasiah, K. S. and Talbot, B. G., (1995). **Active agents and mechanisms of coagulation of turbid waters using *Moringa oleifera*.** Water Research, Vol.29 No.2, pp. 709 – 710.

Ndabigegesere, A. and Narasiah K. S., (1998a). **Use of *Moringa oleifera* seeds as primary coagulant in wastewater treatment.** Environmental Technology, Vol. 19, No. 8, pp.789-800.

Ndabigegesere, A. and Narasiah K. S., (1998b). **Quality of water treated by Coagulation using *Moringa oleifera* seeds.** Water Research, Vol.3, No.10, pp.781-791.

Okuda, T., Aloysius, U. B., Wataru, N. and Okada, M., (1999). **Improvement of extraction method of coagulation active components from *Moringa oleifera* seed.** Water Research. Vol.33 No.15, pp.3373–3378.

Olsen, A., (1987). **Low Technology Waters Purification by Bentonite clay and *Moringa oleifera* seed Flocculation in Sudanese village effects on Schistomaisis Mansonicericariae**. Water Research, Vol. 21, pp.81-91.

Özacar, M. and Sengil, I. A., (2000). **Effectiveness of tannins obtained from valonia as a coagulant aid for dewatering of sludge.** Water Research, Vol.34, No.4, pp.1412.

Pan J. R. Huang. C., Chen, S. and Chung, Y. - C., (1999). **Evaluation of a modified chitosan biopolymer for coagulation of colloidal particles.** Colloidal and surface A: physiochemical and Engineering Aspects, Vol.147, pp.359-364.

Powell, S. T., (1954). **''Water Conditioning for Industry''**, McGraw Hill New York.

Raghuwanshi, P. K., Mandloi, M., Sharma, A. J., Malviya, H. S. and Chaudhari, S., (2002). **Improving filtrate quality using agro-based materials as coagulant-aid.** Water Quality Research Journal Canada. Vol.37 pp.745-756.

Sani M. A., (1990). **The use of Zogale seeds for water treatment**. B. Eng., Final year project report, Bayero University, Kano, Nigeria.

Schultz, C. R. and Okun, D., (1983). **Treating surface waters for communities in developing countries.** Journal of American Water Work Association. Vol.75, pp.212–219.

Schwarz Dishna, (2000). **Water Clarification using *Moringa oleifera*,**
Gate Information Service,Germany,
http://www.deutsch-aethiopischer-verein.de/Gate Moringa.pdf
(Retrieved 15th of December 2007)

Sharma, P., Kumari, P., Srivastava, M. M. and Srivastava, S., (2006). **Removal of cadmium from aqueous system by shelled *Moringa oleifera* Lam**. Seed powder, Biores. Technol. Vol. 97 pp.299–305.

Talbot, B. G., Brian, C. J. and Naes, A. U., (1995). **Active agents and mechanism of coagulation of turbid waters using *Moringa oleifera*.** Water Research. Vol.29, pp.703-710.

Trees for life, 2006, St Louis, Kansas, USA,
http://www.treesforlife.org/project/moringa/default.en.asp
(Retrieved 14th of December 2007)

Tripathi, P. N., Chaudhuri, M. and Bokil, S. D., (1976). **Nirmali seeds – a natural occurring coagulant.** Indian Journal Environmental Health, Vol.18, No.4, pp.272-281.

U.S Environmental Protection Agency, 2007
http://www.epa.gov/safewater/hfacts.html
(Retrieved 20th of December 2007)

USEPA, (1999). **National primary drinking water regulations: disinfectant and disinfection** byproducts D/DBP, Final Rule. EPA 69398-9476.

WELL, 1999
Water, Engineering and Development Centre, Loughborough University, UK
http://www.lboro.ac.uk/well/resources/technical-briefs/60-water-clarification-using-moringa-oleifera-seeds.pdf
(Retrieved 12th of December 2007)

World Health Organization, (2004). **Guidelines for drinking water quality.** Third Edition, Vol. 1 Recommendations.Printed in China by Sun Fung. 540 p.

World Health Organization, 2007
http://www.who.int/topics/drinking water/en/
(Retrieved 12th of December 2007)

WHO/UNICEF, (2005). **Joint monitoring programme for water supply and sanitation.** Water for life: making it happen. Printed in France. WHO Press. 38 p.

APPENDICES

APPENDIX A

Table 5.1: The pH Results of the Jar Tests Using Alum and *Moringa oleifera* for initial Turbidity of 40 NTU

Dosage (ml)	5.5			6.0			6.5			7.0			7.5			8.0		
Raw Water	6.90			6.90			6.90			6.90			6.90			6.90		
Alum	5.90			5.90			5.80			5.80			5.70			5.70		
Settling Time (Hours)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1% Moringa	7.04	7.00	7.00	7.06	7.01	7.00	7.07	7.03	7.03	7.06	7.03	7.03	7.06	7.05	7.03	7.07	7.05	7.03
2% Moringa	6.88	6.90	6.91	6.98	6.91	6.92	6.96	6.92	6.93	6.94	6.93	6.94	6.92	6.96	6.95	6.88	6.94	6.90
3% Moringa	7.05	7.03	7.00	7.06	7.02	7.02	7.05	7.08	7.04	7.10	7.10	7.07	7.10	7.12	7.07	7.12	7.13	7.06
4% Moringa	7.03	7.01	7.10	7.01	7.01	7.13	7.02	7.08	7.14	7.05	7.15	7.15	7.07	7.16	7.15	7.03	7.16	7.15
5% Moringa	7.05	7.11	7.09	7.07	7.12	7.10	7.10	7.16	7.04	7.12	7.16	7.15	7.13	7.14	7.18	7.14	7.16	7.18
6% Moringa	7.04	7.12	7.16	7.08	7.13	7.14	7.10	7.14	7.13	7.11	7.16	7.12	7.14	7.16	7.10	7.14	7.16	7.00
7% Moringa	7.07	7.01	7.08	7.07	7.03	7.09	7.12	7.05	7.14	7.14	7.06	7.14	7.16	7.07	7.15	7.13	7.10	7.15
8% Moringa	7.08	7.09	7.07	7.06	7.11	7.09	7.04	7.13	7.08	7.01	7.14	7.10	7.00	7.16	7.11	7.00	7.19	7.11
9% Moringa	7.02	7.00	7.06	7.04	7.0	7.06	7.03	7.00	7.07	7.04	7.01	7.09	7.04	7.00	7.09	7.03	7.03	7.09
10% Moringa	7.07	7.06	7.01	7.10	7.08	7.60	7.13	7.11	7.10	7.16	7.13	7.10	7.17	7.13	7.11	7.17	7.13	7.11

Table 5.2: The Turbidity Results of the Jar Tests Using Alum and *Moringa oleifera* for initial Turbidity of 40 NTU

Dosage (ml)	5.5			6.0			6.5			7.0			7.5			8.0		
Raw Water (NTU)	40			40			40			40			40			40		
Alum (NTU)	23			13			7			4			3			2		
Settling Time (Hours)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1% Moringa	22	20	19	27	24	23	25	20	17	22	14	15	20	13	12	15	11	11
2% Moringa	17	12	11	25	17	15	17	11	11	13	8	9	16	9	8	14	8	7
3% Moringa	10	10	9	10	8	8	9	8	8	8	7	6	8	6	5	10	8	7
4% Moringa	7	5	6	20	14	12	13	6	5	14	8	7	12	9	6	7	8	5
5% Moringa	11	7	8	17	10	9	16	9	8	9	6	6	14	9	8	7	5	6
6% Moringa	10	7	5	19	12	9	11	7	6	8	5	3	15	8	6	9	7	5
7% Moringa	8	7	4	11	6	5	7	6	5	9	4	5	7	4	5	10	6	5
8% Moringa	12	8	7	15	4	6	10	7	5	6	4	4	12	7	6	9	6	5
9% Moringa	13	8	6	27	14	9	16	9	5	12	5	3	22	12	9	13	7	4
10% Moringa	11	6	9	9	6	6	10	8	7	9	8	7	9	8	6	8	6	8

Table 5.3: The Colour Results of the Jar Tests Using Alum and *Moringa oleifera* for initial Turbidity of 40 NTU

Dosage (ml)	5.5			6.0			6.5			7.0			7.5			8.0		
Raw Water (HU)	220			220			220			220			220			220		
Alum (HU)	134			100			51			32			27			25		
Settling Time (Hours)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1% Moringa	123	117	104	139	135	125	127	111	103	93	79	74	90	70	69	88	67	62
2% Moringa	103	69	76	139	100	84	90	60	57	70	51	44	70	57	47	71	44	33
3% Moringa	58	42	41	54	32	33	49	28	30	45	23	24	45	24	23	47	24	24
4% Moringa	51	32	28	70	68	68	35	34	28	41	41	23	37	38	19	14	21	16
5% Moringa	55	29	31	89	45	44	83	33	39	74	29	33	76	40	40	39	17	24
6% Moringa	56	25	16	106	71	45	66	43	24	37	22	22	88	45	22	55	33	17
7% Moringa	57	28	19	39	33	31	30	22	17	39	23	22	27	25	21	37	24	16
8% Moringa	90	40	22	89	44	35	90	40	28	47	21	20	43	20	20	41	18	20
9% Moringa	70	40	40	77	71	51	71	54	30	60	23	38	99	76	64	70	34	28
10% Moringa	39	28	33	52	35	34	52	38	33	43	41	34	64	41	35	46	36	31

Table 5.4: The pH Results of the Jar Tests Using Alum and *Moringa oleifera* for initial Turbidity of 27 NTU

Dosage (ml)	5.5			6.0			6.5			7.0			7.5			8.0		
Raw Water	6.90			6.90			6.90			6.90			6.90			6.90		
Alum	5.92			5.80			5.77			5.72			5.68			5.53		
Settling Time (Hours)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1% Moringa	7.04	7.06	7.08	7.04	7.06	7.09	7.04	7.06	7.09	7.05	7.06	7.10	7.06	7.11	7.14	7.10	7.13	7.14
2% Moringa	7.07	7.01	7.07	7.07	7.03	7.08	7.08	7.04	7.08	7.09	7.07	7.09	7.10	7.08	7.10	7.10	7.09	7.10
3% Moringa	7.05	7.07	7.09	7.05	7.07	7.10	7.05	7.07	7.10	7.06	7.07	7.11	7.07	7.12	7.15	7.11	7.14	7.15
4% Moringa	7.04	7.06	7.06	7.06	7.06	7.07	7.07	7.07	7.07	7.09	7.08	7.08	7.10	7.09	7.09	7.10	7.09	7.09
5% Moringa	7.00	7.06	7.05	7.01	7.05	7.06	7.02	7.07	7.08	7.03	7.07	7.11	7.03	7.08	7.16	7.04	7.09	7.16
6% Moringa	7.00	7.01	7.00	7.00	7.02	7.01	7.01	7.02	7.01	7.03	7.02	7.05	7.07	7.07	7.06	7.10	7.10	7.08
7% Moringa	7.06	7.08	7.00	7.04	7.08	7.01	7.04	7.07	7.03	7.02	7.08	7.05	7.09	7.08	7.09	7.06	7.08	7.12
8% Moringa	7.00	7.00	7.07	7.00	7.01	7.08	7.00	7.02	7.09	7.00	7.03	7.09	7.00	7.06	7.10	7.02	7.07	7.10
9% Moringa	7.06	7.06	7.08	7.07	7.08	7.09	7.07	7.10	7.12	7.09	7.14	7.15	7.11	7.15	7.17	7.12	7.16	7.18
10% Moringa	7.03	7.03	7.05	7.01	7.05	7.07	7.00	7.07	7.11	7.00	7.07	7.15	7.00	7.08	7.18	7.02	7.13	7.18

Table 5.5: The Turbidity Results of the Jar Tests Using Alum and *Moringa oleifera* for initial Turbidity of 27 NTU

Dosage (ml)	5.5			6.0			6.5			7.0			7.5			8.0		
Raw Water (NTU)	27			27			27			27			27			27		
Alum (NTU)	12			13			5			6			2			2		
Settling Time (Hours)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1% Moringa	37	31	28	36	30	28	33	29	25	34	29	22	33	28	22	30	27	22
2% Moringa	26	26	20	25	22	17	23	22	15	23	19	15	20	18	14	16	17	9
3% Moringa	10	7	7	10	6	6	9	6	6	10	5	4	8	4	4	8	4	3
4% Moringa	16	12	8	14	12	6	14	11	7	14	9	8	12	10	7	14	8	6
5% Moringa	12	10	14	13	9	12	10	10	12	10	8	8	10	7	8	8	7	9
6% Moringa	11	10	9	10	8	9	10	8	10	11	8	9	10	10	10	9	8	7
7% Moringa	11	11	13	9	10	14	10	10	13	9	8	13	8	8	9	9	9	10
8% Moringa	13	7	7	7	8	7	6	7	4	10	5	5	11	5	7	11	6	4
9% Moringa	14	12	8	11	7	7	9	8	8	8	9	7	9	9	7	9	8	6
10% Moringa	9	13	10	10	10	12	12	11	13	14	12	13	15	13	13	16	14	14

Table 5.6: The Colour Results of the Jar Tests Using Alum and *Moringa oleifera* for initial Turbidity of 27 NTU

Dosage (ml)	5.5			6.0			6.5			7.0			7.5			8.0		
Raw Water (HU)	137			137			137			137			137			137		
Alum (HU)	61			48			24			24			14			10		
Settling Time (Hours)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1% Moringa	92	81	93	90	80	92	86	79	85	84	78	77	84	76	75	80	73	75
2% Moringa	72	79	65	63	63	47	62	61	44	54	55	39	51	53	36	43	37	30
3% Moringa	29	28	24	24	20	18	19	15	16	19	15	15	17	12	12	17	11	10
4% Moringa	30	27	24	26	23	19	23	20	17	20	19	19	22	18	16	20	15	17
5% Moringa	35	28	29	31	25	21	29	21	21	26	21	24	24	22	24	27	24	20
6% Moringa	31	24	28	29	24	25	31	23	24	27	22	24	29	24	26	29	23	21
7% Moringa	26	29	31	26	27	31	24	26	26	25	22	26	24	21	23	26	20	24
8% Moringa	30	29	26	29	26	18	31	27	14	33	26	14	30	27	15	25	21	16
9% Moringa	29	25	24	29	23	28	24	22	21	24	22	20	23	23	22	23	21	16
10% Moringa	26	21	24	29	26	28	33	28	30	42	35	32	44	37	38	40	38	40

Table 5.7: Average Turbidities and Colours for initial Turbidity of 40 NTU

Moringa Concentration (g/100 ml)	Mean Turbidity (NTU	Mean Colour (HU)
1% Moringa	18.3	98.7
2% Moringa	12.7	70.3
3% Moringa	8.1	35.9
4% Moringa	9.1	36.9
5% Moringa	9.2	45.6
6% Moringa	8.4	44.1
7% Moringa	6.3	28.3
8% Moringa	7.4	40.4
9% Moringa	10.8	55.3
10% Moringa	7.8	39.7

Table 5.8: Average Turbidities and Colours for initial Turbidity of 27 NTU

Moringa Concentration (g/100 ml)	Mean Turbidity (NTU)	Mean Colour (HU)
1% Moringa	29.1	82.2
2% Moringa	19.3	53.0
3% Moringa	6.5	18.7
4% Moringa	10.4	20.8
5% Moringa	9.8	25.1
6% Moringa	9.3	25.8
7% Moringa	10.2	25.4
8% Moringa	7.2	24.3
9% Moringa	8.7	23.3
10% Moringa	12.4	32.8

Table 5.9: The Jar Test Results of 1% Alum for initial Turbidity of 105 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.10	6.10	6.10	6.00	5.90	5.90	5.80
Colour (HU)	550	90	65	50	40	35	30
Turbidity (NTU)	105	27	21	14	10	9	9
Suspended Solids (mg/l)	93	18	11	6	8	5	4
Alkalinity (mg/l)	110	55	51	45	40	33	27
Hardness (mg/l)	31	33	33	34	34	34	35
Sludge (g)	-	0.9	0.9	0.9	1.0	1.2	1.2

Table 5.10: The Jar Test Results of 3% *Moringa oleifera* at One Hour Settling Time for initial Turbidity of 105 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.10	7.01	7.02	7.03	7.04	7.04	7.05
Colour (HU)	550	70	68	60	50	52	50
Turbidity (NTU)	105	27	24	21	21	21	20
Suspended Solids (mg/l)	93	17	14	11	8	6	7
Alkalinity (mg/l)	110	109	110	110	108	110	110
Hardness (mg/l)	31	35	34	35	33	33	35
Sludge (g)	-	-	-	-	-	-	-

Table 5.11: The Jar Test Results of 3% *Moringa oleifera* at Two Hours Settling Time for initial Turbidity of 105 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.10	7.02	7.04	7.03	7.04	7.03	7.05
Colour (HU)	550	50	48	40	32	34	29
Turbidity (NTU)	105	17	14	11	10	11	6
Suspended Solids (mg/l)	93	9	10	8	6	5	4
Alkalinity (mg/l)	110	109	110	110	108	110	110
Hardness (mg/l)	31	35	34	35	33	33	35
Sludge (g)	-	0.4	0.4	0.5	0.5	0.5	0.6

Table 5.12: The Jar Test Results of 1% Alum for initial Turbidity of 80 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.0	6.0	6.0	6.0	5.90	5.80	5.70
Colour (HU)	417	90	80	48	45	35	25
Turbidity (NTU)	80	24	17	17	7	5	4
Suspended Solids (mg/l)	72	17	9	11	6	5	4
Alkalinity (mg/l)	120	68	63	58	55	58	56
Hardness (mg/l)	30	30	35	34	33	37	40
Sludge (g)	-	0.8	0.9	1.0	1.0	1.0	1.2

Table 5.13: The Jar Test Results of 3% *Moringa oleifera* at One Hour Settling Time for initial Turbidity of 80 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.0	7.04	7.04	7.04	7.05	7.05	7.05
Colour (HU)	417	75	60	60	58	55	48
Turbidity (NTU)	80	18	17	15	13	14	12
Suspended Solids (mg/l)	72	8	15	14	8	8	7
Alkalinity (mg/l)	120	119	120	118	118	120	120
Hardness (mg/l)	30	33	33	34	33	34	35
Sludge (g)	-	-	-	-	-	-	-

Table 5.14: The Jar Test Results of 3% *Moringa oleifera* at Two Hours Settling Time for initial Turbidity of 80 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.0	7.10	7.10	7.08	7.07	7.07	7.05
Colour (HU)	417	60	53	47	41	35	28
Turbidity (NTU)	80	16	15	14	10	8	5
Suspended Solids (mg/l)	72	8	8	7	6	5	4
Alkalinity (mg/l)	120	119	120	118	118	120	120
Hardness (mg/l)	30	33	33	34	33	34	35
Sludge (g)	-	0.3	0.3	0.4	0.4	0.4	0.5

Table 5.15: The Jar Test Results of 1% Alum for initial Turbidity of 61 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.0	6.20	6.20	6.10	6.10	6.0	6.0
Colour (HU)	321	70	50	45	30	25	20
Turbidity (NTU)	61	26	15	10	8	7	5
Suspended Solids (mg/l)	47	10	9	8	7	7	5
Alkalinity (mg/l)	110	50	51	51	50	45	50
Hardness (mg/l)	44	46	45	37	45	45	46
Sludge (g)	-	0.6	0.6	0.7	0.7	0.8	0.8

Table 5.16: The Jar Test Results of 3% *Moringa oleifera* at One Hour Settling Time for initial Turbidity of 61 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.0	7.07	7.07	7.09	7.09	7.09	7.09
Colour (HU)	321	60	57	52	48	49	46
Turbidity (NTU)	61	18	16	13	14	13	12
Suspended Solids (mg/l)	47	7	6	6	8	7	7
Alkalinity (mg/l)	110	110	111	110	110	109	110
Hardness (mg/l)	44	48	43	50	50	48	49
Sludge (g)	-	-	-	-	-	-	-

Table 5.17: The Jar Test Results of 3% *Moringa oleifera* at Two Hours Settling Time for initial Turbidity of 61 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.0	7.08	7.10	7.08	7.09	7.10	7.09
Colour (HU)	321	50	52	46	40	37	24
Turbidity (NTU)	61	17	16	12	10	8	5
Suspended Solids (mg/l)	47	6	5	5	4	3	5
Alkalinity (mg/l)	110	110	111	110	110	109	110
Hardness (mg/l)	44	48	43	50	50	48	49
Sludge (g)	-	0.2	0.2	0.2	0.3	0.3	0.3

Table 5.18: The Jar Test Results of 1% Alum for initial Turbidity of 42 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.10	5.90	5.90	5.80	5.75	5.70	5.60
Colour (HU)	206	55	40	38	32	23	18
Turbidity (NTU)	42	17	15	9	8	5	4
Suspended Solids (mg/l)	21	8	8	6	5	4	4
Alkalinity (mg/l)	115	64	60	55	50	48	35
Hardness (mg/l)	32	34	34	35	35	36	36
Sludge (g)	-	0.4	0.6	0.7	0.7	0.7	0.8

Table 5.19: The Jar Test Results of 3% *Moringa oleifera* at One Hour Settling Time for initial Turbidity of 42 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.10	7.05	7.05	7.07	7.08	7.09	7.10
Colour (HU)	206	58	52	40	38	38	36
Turbidity (NTU)	42	17	17	13	12	11	11
Suspended Solids (mg/l)	21	7	8	6	5	7	6
Alkalinity (mg/l)	115	115	115	113	115	112	113
Hardness (mg/l)	32	34	34	36	35	36	35
Sludge (g)	-	-	-	-	-	-	-

Table 5.20: The Jar Test Results of 3% *Moringa oleifera* at Two Hours Settling Time for Initial Turbidity of 42 NTU

Dosage (ml)	Raw water	5.5	6.0	6.5	7.0	7.5	8.0
pH	7.10	7.05	7.05	7.06	7.08	7.08	7.10
Colour (HU)	206	42	41	38	30	24	22
Turbidity (NTU)	42	16	14	12	10	7	5
Suspended Solids (mg/l)	21	7	7	5	5	5	4
Alkalinity (mg/l)	115	115	115	113	115	112	113
Hardness (mg/l)	32	34	34	36	35	36	35
Sludge (g)	-	0.2	0.2	0.4	0.3	0.4	0.4

Appendix B

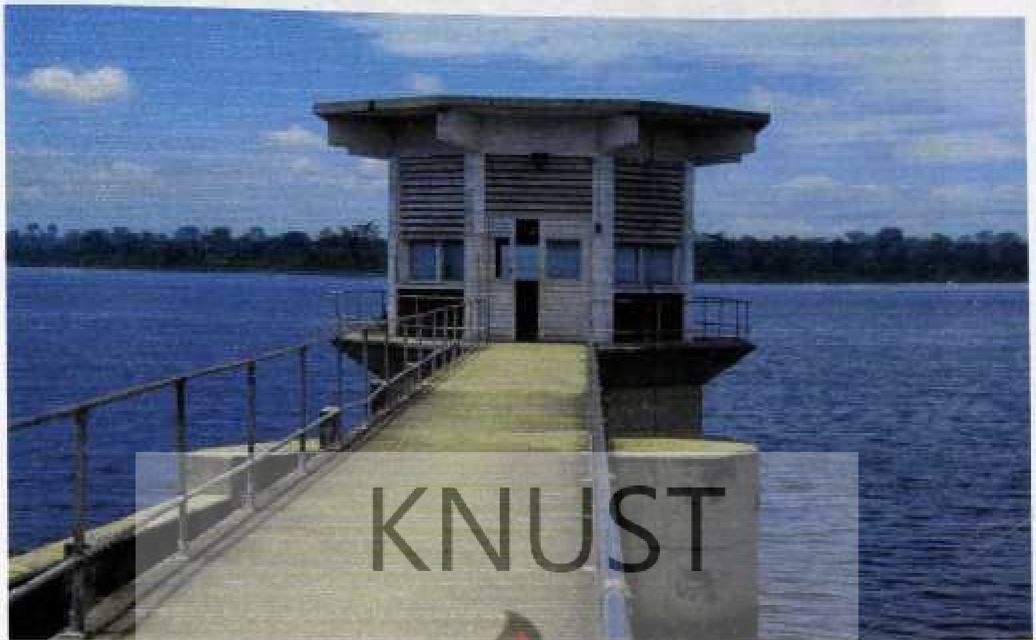

Plate 1: The Barekese Dam

Plate 2: Jar test equipment in action

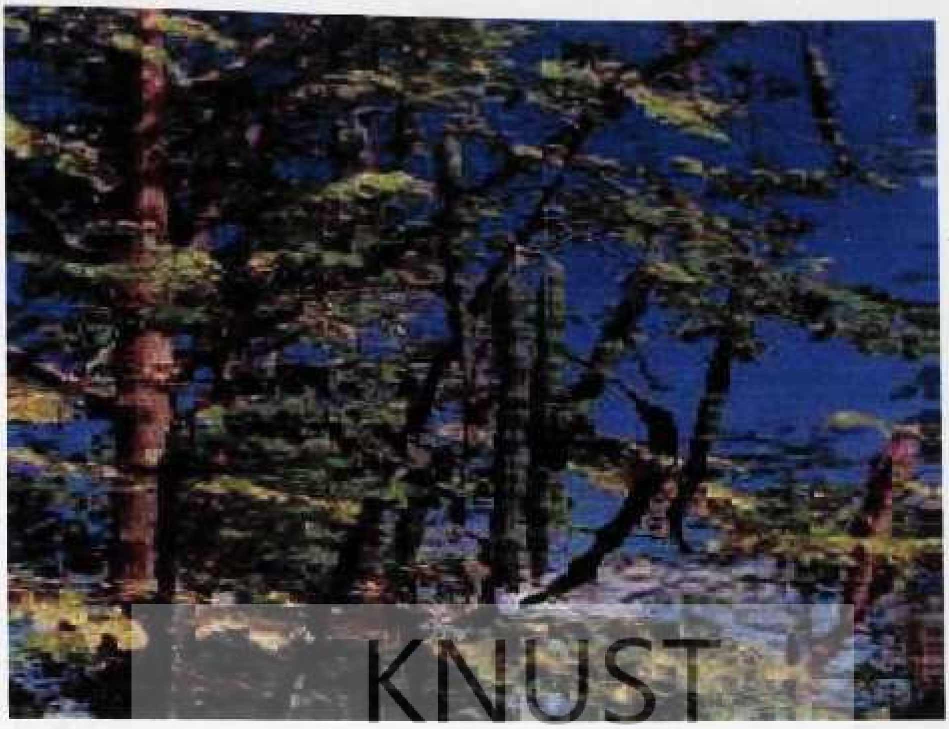

Plate 3: The *Moringa oleifera* plant showing pods that contain the seed

Plate 4: Moringa Pod, Seeds, Fine Powder